EFFECTS ON THE RED-COCKADED WOODPECKER
FROM VARIOUS SPATIAL AND TEMPORAL
APPLICATIONS OF MANAGEMENT PRACTICES

THESIS

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AFIT/GEE/ENV/01M-18

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Abstract

The Red-Cockaded Woodpecker (RCW) is an endangered species endemic to the southeastern pine forests in the United States. RCWs are cooperative breeding birds that live together in clusters of old-growth pine trees (over ninety years old) in which they construct their nesting cavities. The cavities are constructed in living pines, which are predominantly longleaf pines. RCWs also forage upon older pines (over thirty years old) for their mainly insect diet. Moreover, RCWs prefer to forage on longleaf pines.

There are many Department of Defense (DoD) installations in the southeastern United States that contain RCW populations. The Endangered Species Act, along with other DoD regulations, requires installations to protect the RCWs and restore their habitat. Different strategies are used to manage the RCW. A popular management practice converts off-site (non-native) pines back to a region's indigenous pines. Conversion provides the best long-term RCW habitat; however, the initial habitat fragmentation from off-site pine removal may be detrimental to RCW populations.

Shaw AFB, SC manages a small RCW population on the Poinsett Weapons Range (PWR). Conversion from off-site slash pines to longleaf pines has been incorporated on the PWR. Shaw AFB would like to find optimal conversion rates that will not adversely affect the PWR RCW population. A spatially-explicit system dynamics model that incorporated foraging quality and group dynamics was constructed to address Shaw AFB's conversion question. The model showed the resultant PWR RCW population level and behavior from a range of conversion settings used with different management strategies. The model output provides the PWR managers insight on the effects to the PWR RCW population from different management strategies.

EFFECTS ON THE RED-COCKADED WOODPECKER FROM VARIOUS SPATIAL AND TEMPORAL APPLICATIONS OF MANAGEMENT PRACTICES

1. Introduction

Background

The longleaf pine forests of the 1800s dominated as much as ninety million acres of southern pine forests in the southeastern United States. At the end of the 1800s, westward expansion and the growth of the timber industry in the southeastern United States started to clear virgin longleaf pine forests (Boyer and Peterson, 1983:157; Landers and others, 1995:39; Jackson, 1995:43). The Red-Cockaded Woodpecker (*Picoides borealis*) is an endangered species endemic to open old-growth southern pine forests (Ligon, 1970:255; Jackson, 1977a:448) and is argued to be a keystone species that indicates the longleaf ecosystem's health (Conner and others, 1997b:139). As the longleaf pine forests of the southeast declined, so too did the Red-Cockaded Woodpecker (RCW) metapopulation (entire species population) to about 2,666 groups in 1982. A group consists of at least a RCW breeding male and female, and includes adolescent birds and helping birds which assist in the rearing of the young (Lennartz and others, 1983:7; Dickson, 1991:31; Jackson, 1995:43). Today, roughly three million acres (3 ½ % of the late 1800s forests) of the old-growth longleaf pine forests remain (Landers et al., 1995,39). The RCW metapopulation has risen modestly due to intensive management practices to approximately 5,000 groups distributed throughout the southeastern United States (Costa and Walker, 2000:n. pag.; USFWS, 2000:vi). The future sustainment and existence of the RCW is dependent upon allowing the southern pine forests to return to

their dominant old-growth condition. To assist the reader, a glossary of terms and acronyms is included at the beginning of Appendix A.

Many Department of Defense (DoD) installations throughout the southeastern United States contain populations of RCWs, including Eglin AFB, FL; Fort Bragg, NC; Camp LeJeune, NC; Fort Benning, GA; and Shaw AFB, SC (James, 1995b;444-447). Guided by the Endangered Species Act (ESA) and 2000 RCW Recovery Plan prescribed by the United States Fish & Wildlife Service (USFWS), installations assume stewardship of the RCW. In 1994, the DoD proclaimed proactive restorative environmental policies in performing its missions by the *Ecosystem Management Policy Directive* (Leslie and others, 1996:17). This policy includes proper threatened and endangered (T&E) species management. Furthermore, Air Force Instruction 32-7064, *Integrated Natural Resources Management*, requires that all installations must prepare and maintain a current inventory of T&E species and habitats as part of a base habitat inventory (DAF, 1997:13). Taking on the additional mission to properly manage and preserve the RCWs and their habitat, along with carrying out installation's other missions, presents an intricate challenge. Often, the areas that support the best mission training platforms also provide some of the best habitat for the RCW. Failure to develop strategies that support both training needs and RCW conservation requirements results in the loss or restrictions of critical training regions on installations (Sneddon, 1995:36-39). Commanders can face penalties, fines, and even imprisonment for knowingly violating regulations for protecting the RCW (Vaughan, 1994:78, 84). A long-term sustainable and economical approach in performing all missions concurrently on installations needs to be established.

The RCW was classified as an endangered species in 1970 due to habitat loss in 35 Federal Register 16047, 13 Oct 1970 (FR, 1970:Appendix D). Unlike other woodpeckers, the RCW excavates its roosting and nesting cavities out of the heartwood of living old-growth pines (Jackson, 1977b:160). The preferred cavity tree of the RCW is the longleaf pine (*Pinus palustris*). Depending on the forest type, RCWs will also excavate cavities in loblolly pine (*P. taeda*), shortleaf pine (*P. echinata*), and sometimes in slash pine (*P. elliottii*), pond pine (*P. serotina*), or sand pine (*P. clausa*) (Lennartz and others, 1987:48; Bowman and Huh, 1995:426). RCWs are territorial, non-migratory, cooperative breeding birds. They live together in groups and reside in clusters of old-growth pine cavity trees (Ligon, 1970:255; USFWS, 2000:vii). RCWs prefer to forage on insect prey from older pines, predominantly longleaf pines (Hooper, 1996:127; Hanula and others, 2000:60). RCWs also forage on other pines within their territories such as the slash pine (Porter and Labisky, 1986:245). The extent of the RCW's dependence on non-longleaf pines is unclear. Due to its many eccentricities, an intriguing challenge is presented in bringing the RCW to full recovery.

The United States Congress passed the Endangered Species Act (ESA) in 1973 to protect species of plants and animals that were in danger of becoming extinct. The act itself is comprised of 18 sections, in which three major sections make up the working structure of the ESA (Vaughan, 1994:18). The U. S. Fish and Wildlife Service (USFWS) oversee the management of the RCW and approve recovery plans from locations that contain RCWs. Ecosystem mangers must ensure that mission activities do not jeopardize the existence of T&E species and their habitats (Vaughan, 1994:38-40). Therefore, DoD commanders are bound to meet regulatory requirements for species protection (Leslie et

al. 1996:93). The ESA is the main driver for the extensive management attention given to the RCW.

RCWs are relatively small birds. An adult RCW is 8 to 9 inches in length and is discernable by its large white cheek patches and zebra stripped pattern on its wings (USFWS, 2000:9). The male RCW has a small cluster "cockade" of red feathers on the side of its head. The cockade is easily distinguishable on male fledglings but then shrinks as they mature (Jackson, 1995:42). As a cooperative breeder, the RCW is often assisted in the raising of its young by other RCW "helpers" (Ligon, 1970:267-268). A group of RCW consists of a male and female breeding pair, their fledglings, and any helpers. Helpers are often male offspring of the breeding male and female from previous years. Eventually a helper will either assume the group's breeding male role if the breeding male dies or the helper will become solitary and leave the group in search of a new group. The breeding female will leave the group if she is the mother of a helper that assumes the group's breeding male role (Walters, 1988:299-300).

Since the RCW is a territorial and non-migratory bird (Beckett: 1974:3), its overall health is sensitive to the proximity of other RCWs and to the quality of local foraging and nesting habitats (Ligon, 1970:258). The RCW prefers to excavate its roosting and nesting cavities from the softened heartwood of old-growth longleaf pines, approximately ninety years old or older (USFWS, 1985:5-6; Hooper, 1988:392). The heartwood softens due to the onset of red heart fungus (*Phellinus pini*) infection (Beland, 1971:125; Jackson, 1977b:160). Mature longleaf pines and other types of pine trees provide the foraging habitat for the RCW. The older trees provide large surface areas for insects to travel on which provides a better foraging opportunity for the RCW (Hanula et

al., 2000:60). The RCW provides and often competes for its available cavities with the southern flying squirrel (SFS) (*Glaucomys volans*) and other species of woodpeckers (Conner, 1995:335). Also, the RCW combats predation from snakes by puncturing holes around the cavity entrance to produce a deterring sap resin layer (Jackson, 1977a:448; Rudolph and others, 1990b:14-15).

Southern pine forests are dynamic sensitive ecosystems. The tree composition includes longleaf pine in combination with either slash pine, loblolly pine, shortleaf pine, sand pine, pond pine, and/or various oak hardwood trees, which are simply referred to as hardwoods (Ware and others, 1993:447-448). Prior to the beginning of wide scale timber harvests in the late 1800s, the longleaf pines dominated the southern forests. Longleaf pine forests stretched from the Carolinas to Texas; now, their numbers are greatly reduced due to clear-cutting, farming, tree conversion, and fire suppression (Ware and others, 1993:453; Landers and others, 1995:39-41). The longleaf pine adapted to the recurrent natural wildfires that swept through southeastern forests. These fires reduced the number of less fire resistant trees and understory growth while stimulating the longleaf pine seed's germination (Wahlenberg, 1946:144). The practice of controlled prescribed burning is recommended to provide for these natural fire-disclimax events of the original southern pine forests (Boyer, 1990:1; Franklin, 1997:13; USFWS, 2000:93-94). Another reason for the dwindling of longleaf pines was the conversion to faster growing pines, such as the slash pine, during the reforestation starting in the early 1900s (Wakely, 1935:6; Little and Dorman, 1954:1; Row, 1960:704; Schmidtling and Hipkins, 1998:1135). This conversion was inappropriate in areas with sandy soils where longleaf pines prospered, but the moisture-requiring slash pine growth was stunted due to the soil

type (Wakely, 1935:67; Hebb and Burns, 1975:6-8; Cain, 1978:5; Beyer and others, 1996:827; USFWS, 2000:99). However, conversion back to longleaf pine is becoming more popular with forest managers.

Conversion of slash pine to longleaf pine is being pursued to restore the classical conditions of the longleaf dominance favorable for RCW habitat (Ferral, 1998:3; USFWS, 2000:99-100). Conversion is advantageous to foresters in that it returns the ecosystem back to its natural sustainable state and reverses previous mistakes of planting off-site (species not native to a region) pines in unsuitable soils. The conversion ultimately creates the desired habitat of the RCW and provides short-term profits from clear-cut slash pine (Beyer et al., 1996:827; Ferral, 1998:3). The short-term effects from the conversion on the RCW population may be detrimental. Reduced slash pine foraging habitat is often thought to have some minimal negative effect on the RCW. At the very least, the fragmentation and spacing of the clear-cutting may have adverse effects on the prognosis of the RCW (Ferral, 1998:3,48). Proper conversion guidance needs to be addressed to limit the detrimental short-term effects on the RCW.

There are numerous management techniques being implemented to protect the RCW. The aforementioned slash pine to longleaf pine conversion is a popular long-term plan for areas where longleaf pines were historically dominated. Understory growth control is necessary to promote long-term health of longleaf pine forests. Prescribed controlled burns are used to kill off underbrush and less fire-resilient trees, return nutrients to the soil, and assist longleaf pinecone opening for seed release (Wahlenberg, 1946:144). Also, herbicide applications are used to kill off hardwoods, which can choke off nutrients to longleaf seedlings and saplings (Brockway and others, 1998:160-161).

There are various short-term methods employed to support RCW population growth in small populations. Human activity around cavity tree clusters is limited (USFWS, 2000:146-148). More intensive management measures include inserting artificial cavity nest boxes (rectangular box birdhouses) into compatible longleaf trees (Krusac and others, 1995:62). Artificial cavities are also created by using a specific drilling technique (Walters and others, 1995b:368). Another method used involves installing hole restrictor plates over the cavities to keep the entry hole to the cavity at a fixed diameter (Carter and others, 1989:70). As the cavity hole gets larger, it is more susceptible to occupation by larger birds and squirrels. Capture and removal of SFSs from RCW cavities is also performed (Franzreb, 1997:460). Additionally, installation of aluminum flashing bands above and below RCW cavities and at the base of trees excludes most SFSs and snakes respectively (Whitgott and others, 1995:397; Montague, 1995:405-407). An involved management practice translocates RCWs from healthy populations into groups needing mates and helpers (Franzreb, 1999:38).

The specific location of interest for this research is the Poinsett Weapons Range (PWR) located in Sumter County, South Carolina and is operated by the United States Air Force at Shaw Air Force Base. The 12,500-forested acre range is composed of roughly an equivalent amount of slash pine and longleaf pine acreage with some loblolly pine dispersed throughout the range (Shaw, 1996a:1). The longleaf pine grows well in the predominately sandy soil of the range. Conversely the off-site slash pine acreage planted in the mid 1900s exhibits stunted growth due to the unfavorable soil conditions (Shaw, 1996c:60, 69). Turkey oaks are spread throughout the understory of the range and are controlled with prescribed burns and herbicide application. The range has a small

isolated population of RCWs consisting of approximately 25 birds. The RCW population inhabits five active cavity tree clusters throughout the range (Ryan D., pers. comm..). The focus of the research is on the PWR ecosystem in particular, but the knowledge gained will be applicable to the management of the southern forest ecosystems overall.

Purpose of Research

The purpose of this research is to provide ecosystem managers of southern pine forests insight into the relationship between the RCW and its nesting and foraging habitat. This insight should foster forest management practices that help the endangered RCW by restoring its natural habitat. In turn, the application of the management practices can be presented to the proper regulators for acceptance of use on Federal lands.

Problem Statement

Ecosystem managers want to maximize the sustainable effectiveness of their resources in meeting the RCW management needs. RCW managers incorporate a variety of forest management and RCW management practices to support the RCW and its habitat. The popular forest management practice that converts off-site slash pine to longleaf pine ultimately produces optimal RCW foraging and nesting habitat while also providing timber harvest funds to offset management costs. The interim effects on the RCW from reduced slash pine foraging habitat needs to be clarified to drive proper management decisions. Furthermore, the effectiveness of management practices, both individually and collectively, needs exploration to establish best management strategies.

Research Objectives/Questions

A system dynamics approach will be used to simulate over a long period of time how the southern forest ecosystem functions. System dynamics allows theorization on

how the ecosystem behaves under unfamiliar conditions due to an absence of actual data (Meadows, 1980:31). System dynamics methodology is ideal for addressing the issues of the problem statement. Through this modeling effort, the following objectives will be addressed:

1. Develop a spatially-explicit system dynamics model of the PWR RCW population that relates cooperative breeding behavior and foraging quality levels to the movement of individual birds and also incorporates various management inputs.

2. Explore the resultant behavior of the RCW population under different combinations of forest management and RCW management practices.

3. Determine the optimal rate, size, and layout of the conversion from slash pine to longleaf pine that does not adversely affect the short-term status of the RCW.

4. Improve the understanding and distinguish the mechanisms of the slash pine's role in the RCW's foraging habitat.

2. Literature Review

RCW Distribution

Currently, there are approximately 5,000 groups of RCWs located throughout twelve states in the southeastern United States (USFWS, 2000:vi). A group consists of at least a breeding male and female, and includes helpers and fledglings. The RCW metapopulation (entire species population), located only in the United States, is segregated into different populations of various sizes from large healthy populations to small isolated groups. The metapopulation, shown in Figure 1, consists of three large populations of approximately 500 groups each, roughly ten populations between 100 - 300 groups each, and numerous small isolated populations of less than 100 groups each (USFWS, 2000:177-178). A majority of the RCWs live on government owned lands such as national and state forests as well as DoD installations (Jackson, 1994:160). There

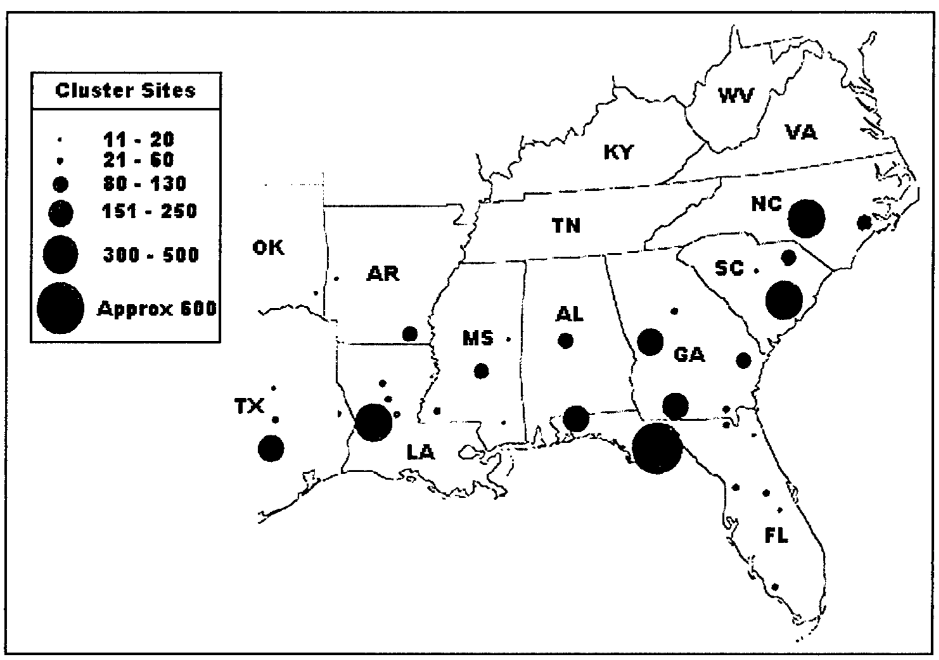

Figure 1: Red Cockaded Woodpecker Population Size Distribution (modified after James, 1995b:443)

are fewer than 1,000 RCW groups dispersed on private lands (Costa 1995b:68). With the tremendous loss of its original late-1800 habitat, RCWs are now dependent on government lands for their livelihood and recovery. Achieving long-term self-sustainment of the once widespread RCW metapopulation in the southeastern United States is a daunting undertaking. Recovery will take intensive temporary short-term measures as well as long-term habitat restoration.

RCW Status with the Military

Military installations, which contain half of the core RCW populations, play a substantial role in the recovery of the RCW. Shown in Figure 2, there are approximately sixteen DoD installations in the southeastern United States that have RCWs (USFWS, 2000:122). These installations have proactive polices for managing the RCWs, with the level of management involvement dependent upon resources available. The RCW population sizes on these installations range from large populations like at Eglin AFB,

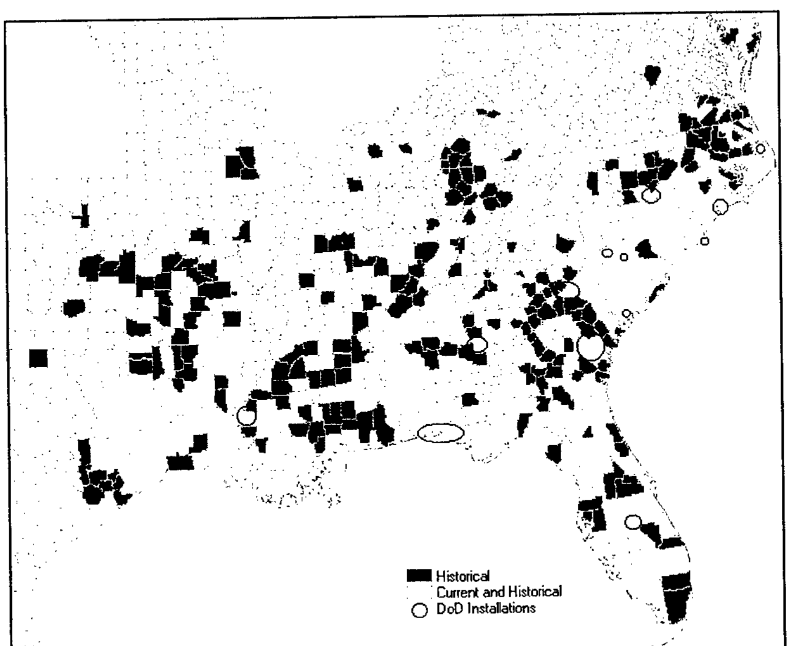

Figure 2: Red-Cockaded Woodpecker Distribution: Historical, Current, & DoD Installations (modified after Costa et al., 2000:n. pag.)

Florida with approximately 280 groups to small populations like at Shaw AFB, South Carolina with 5 groups (Moranz and Hardesty, 1998:24; Ryan D., pers. comm.).

For the most part, proactive policies have worked on DoD installations as RCW populations have greatly increased in the 1990s (USFWS, 2000:122). RCWs live on military installations because the lands are mostly undisturbed from outside influences. Ironically, some military operations aid the RCW. Wildfires that result from explosions on weapon ranges, have provided the once natural fire-dependent forests to which the RCWs adapted (James, 1995a:438). Most RCW clusters can be found near weapon ranges' target areas due to this phenomenon. The military has experienced problems meeting RCW requirements under the ESA with some of these problems resulting in the loss of training land (Leslie et al., 1996:16). It took the threat of legal action by environmental groups to have the USFWS respond to the mismanagement of the RCW at Fort Benning Georgia in 1992. Three civilian employees were indicted for concealing the presence of RCW trees and groups in order to harvest the trees (Nickens, 1993:32, Jackson: 1994:162-163). RCW populations were dropping on DoD installations as with the RCW metapopulation at large. Now, these same installations have become refuges for the RCW and play a critical role in the species recovery.

RCW Ecological Importance

Noted RCW researchers Richard Conner and Craig Rudolph argue that the RCW is a keystone species to the remnant fire-disclimax southern pine forest (Conner et al., 1997b:139). They make the point that the RCWs provide long-lasting tree cavities not only for themselves but also for approximately 24 other species in cavity-barren southern pine forests (Conner and others, 1997a:12, Kappes and Harris, 1995: 389). These forests

contain minimal snags, standing dead trees that other species would normally use for homes. Thus the ability of the RCW to excavate cavities out of living pines is paramount to its survival as well as other tree-cavity dwelling animals (McFarlane, 1992:106; Conner et al., 1997b:141). Critics justly point out that the limited numbers of RCWs cannot provide as many cavities as they once did. However the counter argument to that point is RCW cavities last decades, thus the impact of the RCW is felt well after its death (Bigony, 1991:14; Conner and Rudolph, 1995:349). Additionally, the RCW provides an unaccounted level of insect control in forests (McFarlane, 1992:190; Jackson, 1994:171). It can also be argued that the RCW is an indicator species to the biodiversity of the remaining fire-disclimax southern pine forest ecosystem (Ware and others, 1993:482). Disappearance of the RCW from this ecosystem reflects the direct impact from humans via old-growth timber harvests, introduction of off-site pines, and fire suppression which leads to hardwood encroachment succession (Frost, 1993:30).

Since the listing of the RCW as an endangered species in 1970 and also receiving protection with the passage of the ESA in 1973, there has been an explosion of research performed on the bird. There have been over 150 articles published and approximately 20 graduate theses performed on the RCW (Jackson, 1995:44-47). Also, numerous RCW field studies and reports have been executed. Three symposiums (1971, 1983, 1993) on the RCW have been held that discussed the latest research and published papers on the bird. Needless to say, the RCW has been receiving extraordinary attention from the academic, scientific, and field research communities. These efforts have contributed greatly to development of effective management techniques and public knowledge on the RCW. In areas where this new knowledge is being applied, RCW population numbers

are growing (Jackson, 1994:161). But still, the main concern in the recovery of the RCW is providing and maintaining suitable habitat which will enable self-sustainment.

Endangered Species Act

The United States Congress passed the Endangered Species Act (ESA) in 1973 to protect species of plants and animals that were in danger of becoming extinct. Today, the ESA lists 971 endangered species and 273 threatened species in the United States (USFWS, 2001a:n. pag.). The executive branch under the Secretary of the Interior is the governing authority of the ESA with the Attorney General being the enforcer of the act. State and local governments have their own laws that detail endangered species management and are often stricter than federal laws. Private landowners cannot remove endangered species or their habitat without permission from the proper authorities. However, they do not have to participate in endangered species conservation efforts (USFWS, 2000:106). Since its inception, the ESA has been one of the most wildly debated and impacting pieces of legislation in the environmental arena.

The ESA is comprised of eighteen sections, in which three major sections make up the working structure of the ESA (Vaughan, 1994:18). Section 4 covers how the listing process works and the players involved. A species that is endangered is one whose existence is at stake in the foreseeable future. The Secretary of the Interior has the power to list a species under the ESA through the actions of the USFWS for terrestrial species and the National Marine Fisheries Service (NMFS) for aquatic species. NMFS handles marine and anadromous species (about 5% of all cases) while the USFWS covers all other species. A species is considered to be eligible for the ESA list once a petition from either an individual or organization is received by the USFWS or the NMFS. When

making the determination, the services must consider the following: threats to the habitat, over utilization, disease, predation, inadequacy of current protection, and other scientific factors that are pertinent to the species existence. The services are currently prohibited from considering economic factors in the listing or delisting (Clark and others, 1994:21-26). Whatever the service's decision is, Congress has the right to overrule it through provisions to the ESA.

The second important part of the ESA is Section 7, which indicates the steps that must be taken to protect endangered species and their habitat on federal lands (Clark et al., 1994:23-24). The USFWS oversees the management of the RCW and approves mandated recovery plans from locations that contain RCWs such as National Forests and DoD lands. The USFWS manages RCW populations that are on National Wildlife Refuges (Jackson, 1994:160). As in the case of the DoD, the USFWS can literally halt missions if it finds that the proper management requirements are not being preformed (Leslie et al., 1996:16). With the threat of losing missions, the military takes a proactive stance in managing the RCW and works jointly with the USFWS in protecting the RCW. The Air Force mandates RCW management coordination with the USFWS in AFI 32-7064, *Integrated Natural Resources Management* (DAF, 1997:13).

The last major section of the ESA, Section 9, covers prohibitions against "takings" of listed endangered species. Takings are considered under a broad spectrum including the killing of individual species to the damaging of species habitat (Vaughan, 1994:63-75). This section has been an issue with RCW management and the forestry industry. The environmental group, Sierra Club, filed suit against the United States Forest Service (USFS) in Texas under the takings provision. The USFS produced a

handbook detailing the RCW habitat requirements. When the USFS violated their own handbook requirements in Texas, the Sierra Club used the handbook as grounds to sue the Forestry Service. The result was that the USFS was found in violation of the ESA. (Vaughan, 1994:84). This landmark case established legal precedent nationally stating that "take" also includes failure to maintain suitable habitat for endangered species (Bigony, 1991:16). Section 9 also pertains to decisions that involve relocating RCW groups or translocating individual RCWs. In the effort to recover the RCW, the ESA has been the legal backbone used to protect the bird.

RCW Recovery Plan

First Recovery Plan. A recovery team appointed by the USFWS in 1975 created the first RCW Recovery Plan. Jerome Jackson, a leading RCW biologist, led the team during the process. The team, comprised of experts from the biological and forestry communities, had philosophical disagreements on recovery requirements. A compromise, not a consensus, was finally reached and the approved plan was released in 1979. The team was disbanded in 1982 (McFarlane, 1992:201-205). The plan stated the basic requirements in five steps of action. First, the plan stated that a census should be conducted along with an education campaign on the RCW. Second, management plans were to be created and implemented. Third, reestablishment of RCWs was to be attempted in areas with suitable habitat. Fourth, linking of fragmented populations via corridors was to be performed. And finally, protection of RCWs from takings was to be enacted (USFWS, 1979:10-12). The detailed management provisions of main concern were: a cluster site consisting of an aggregate of cavity trees (without an age stipulation) with a 200 foot buffer zone; a support stand adjacent to the cluster consisting of a

minimum of 40 acres of pines at least sixty years old; a total of 200 acres of contiguous pine forest is required per cluster; and a harvest rotation within the 200 acres (not within the cluster site) of at least eighty years for loblolly pine and one hundred years for longleaf pine (McFarlane, 1992:205). Despite being approved, the plan was not implemented (Bigony, 1991:16). The plan was opposed by the timber industry for placing too many constraints on their harvesting operations, which lead to the USFS to advocate shorter harvest-rotation periods (McFarlane, 1992:203-207).

Second Recovery Plan. To resolve the conflict with the USFS, the USFWS created a new recovery team led this time by Michael Lennartz, a leading woodpecker biologist who worked for the USFS (McFarlane, 1992:207). In 1985, the revised recovery plan was released. Additions to the 1979 plan included in the 1985 plan were: promoting RCW conservation on private lands, requests for more research in areas of specific habitat needs, and set criteria for downlisting and delisting (USFWS, 1985:41, 47-48). The 1985 plan revised and redefined foraging habitat to be: well-stocked (≥ 60 ft^2 basal area [BA, cross-sectional trunk area] per acre) pine and pine-hardwood stands (≥ 50% BA in pine); at least thirty years old and older, with more that 24 pines per acre ≥ 10 inches in diameter at breast height (dbh); and all within a 0.5 mile range of the cluster for a total of 125 acres of acceptable foraging habitat (USFWS, 1985:54). Critics had many complaints about the new 1985 recovery plan. They pointed out that the plan's foraging habitat definition did not mention harvest rotations, which enabled fragmentation of RCW colonies. Another strong criticism voiced was that the plan was based on the healthiest RCW population located in the Francis Marion National Forest, SC, and presented only a single "cookbook" approach for management in the different types of

RCW habitat (McFarlane, 1992:207-208; Jackson, 1994:164). Also up for debate were issues on what represented a stable and recovered population. The 1985 plan stated that populations of 250 groups represented a stable viable RCW population. Downlisting would occur with 6 viable populations and delisting with 15 (USFWS, 1985:43-44). Critics pointed out that 250 groups would not be enough to account for genetic drift losses (Stevens, 1995:237-238; USFWS, 2000:28). The 1985 plan also dropped the original requirements of public education and corridor connections, much to the chagrin of RCW supporters (Jackson, 1994:171). Despite introducing helpful requirements and recommendations, the 1985 RCW plan still left RCW management issues up for debate with critics calling the plan based in "minimalism" (McFarlane, 1992:212).

Latest Recovery Plan. The USFWS in 1995 assembled another recovery team to revise and update the 1985 recovery plan. The USFWS released for review the current draft of the RCW recovery plan in October 2000. The final draft of the 2000 RCW Recovery Plan will be released around late Spring 2001 (USFWS, 2001b:n. pag.). The new plan is the most comprehensive collection of RCW information that covers all aspects pertaining to biology, management techniques and costs, and recovery. The main steps of the first two recovery plans are expanded upon in the 2000 recovery plan with provisions on active cluster protection, requests for more research in specific areas not currently addressed, and a call to address single cluster management costs versus landscape management costs (USFWS, 2000:166-170).

The 2000 recovery plan includes new provisions on habitat composition and quality. The definition of high quality foraging habitat did not change from the 1985 plan. For less than high quality habitat, 200 to 300 acres of foraging habitat is prescribed

per cluster. The plan stipulates three types of silviculture (timber harvest strategy) practices: two-aged management, which creates two distinct age classes under a 100 and 120 year harvest rotation interval for loblolly and longleaf pine respectively; uneven-aged management leaving twenty or more pines per acre of at least 14 inch dbh and sixty years of age; and low intensity management (the different types of silviculture are described later in this chapter). Restoration of off-site pines to native pines should be done in sections no more than 25 acres (USFWS, 2000:155-156, 161-162).

The 2000 recovery plan prescribes five criterions that must be met for the downlisting of the RCW from endangered to threatened and five criterions for complete delisting. Delisting entails removal from T&E species list along with the removal of protections afforded to T&E species. The criterions include minimum population limits that must be achieved in all major core populations (as defined by the USFWS to be 350 potential breeding pairs, estimated 400 to 500 active clusters) and supporting populations (250 potential breeding pairs, estimated 275 to 350 active clusters) as well as achieving stable or increasing population growth trends. The recovery plan estimates RCW downlisting in 2035 and delisting in 2067 (USFWS, 2000: 126-129).

The 2000 recovery plan is being carefully reviewed and critiqued by many leading authorities on the RCW. The plan should help solidify current successful managerial practices and population growth with the eventual complete recovery of the species. "We are at a crossroads in RCW recovery...The outlook of RCW recovery is excellent; our wisdom and knowledge, gathered individually, and collectively shared and put into action, will take us to recovery," Ralph Costa, current USFWS RCW Recovery Program Manager's comments at that 1993 RCW Symposium (Costa, 1995a:5).

General RCW Biology

The RCW is a relatively small woodpecker with distinguishable traits. RCWs average 8 to 9 inches in length with a wingspan of 12 inches (USFWS, 2000:9). Males have a small, not easily visible, cockade of red feathers behind the ear region on the sides of their heads (Ligon, 1970:273). The cockade becomes visible when the bird is excited or provoked (Bigony, 1991:13). The cheeks on the RCW contain large white splotches with the rest of the head being black. The wings of the RCWs have a spotted black and white, zebra-striped design. Their breast feathers display a black and white checkerboard design (USFWS, 2000:9). Figure 3 shows an adult RCW. Fledglings show the adult

Figure 3: Adult Red-Cockaded Woodpecker (USFWS, 2001c:n. pag.)

color traits early on, except for a spiked oval clump of red feathers on the top of the male fledgling's head that eventually disappears with maturity (Ligon, 1970:273). Unlike other birds, males and females are approximately the same size, weighing less than 2 ounces each, and are not easily discernable from a distance (Bigony, 1991:13). A

possible reason for the similar size is that the RCWs need to keep their cavity hole as small as possible to deter larger birds from stealing the cavity (Ligon, 1968:212). Consequently, similar body sizes may be due to the requirement for both the male and female to incubate their eggs in the male RCW's cavity nest. In turn, this would require the cavity hole diameter to enable entrance of both male and female RCWs.

Cooperative Breeding

RCWs are cooperative breeders that live together in groups of two to nine birds. Groups occupy cluster stands of nesting cavity trees. A group consists at bare minimum a mating adult male and female. The breeding male is typically the oldest male in the group. Usually the group will consist of the breeding pair along with their fledglings and helpers. Depending on nestling success, there are from one to three fledglings per group. The helpers are predominately male birds that are typically previous-years' offspring from the breeding RCW pair. Helpers forego their own desire to breed to assist in the raising of the group's fledglings (Hooper and others, 1980:1; Bigony, 1991:13; USFWS, 2000:10-11). RCWs are theorized to have evolved into the cooperative breeding social system due to their reliance on clusters of scarce cavity trees, the saturation of adjacent suitable habitat by other RCW groups, and/or the lack of adjacent suitable habitat to migrate into (Walters et al., 1988:276, 300-301).

Group enlargement occurs mostly when male fledglings remain with the group to become helpers. Male fledglings follow either one of two life-strategies, stay-and-forage (SAF) or depart-and-search (DAS) (Walters and others, 1992:623-624). RCWs opting to SAF have higher survivability rates than RCWs that choose to DAS. Also, RCW males that SAF and later become breeders have higher fecundity rates than RCW males that

DAS. Presumably, these results are due to parenting skills acquired as a helper, added to the fact that RCWs that DAS tend not to acquire quality natal areas (McFarlane, 1992:145-147; Walters et al., 1992:637). Some groups have had up to four helpers but typically groups have no more than two helpers. Helpers assist in the incubation of the clutch eggs, feeding and brooding of the nestlings, and feeding of fledglings (USFWS, 2000:10). A helper will stay with the group until the breeding male dies, during which the helper will assume the role of breeding male, or the helper decides to DAS. The amount of helpers in RCW groups within an area is an indication of the health and long-term robustness of the local RCW population (Walters et al., 1988:298-299; USFWS, 2000:17-18). In-breeding depression resulting in reduced survivability and productivity has been shown in RCW populations. Thus, RCW try to avoid incestuous breeding behavior (Haig and others, 1993:191; USFWS, 2000:26). Female fledglings are forced to leave the group by the breeding female to search for a mate and natal territory. Also, a breeding female will leave her group if one of her helper sons becomes the breeding male (Walters et al., 1988:300; Bigony, 1991:13; McFarlane, 1992:144).

RCWs are sedentary in nature. RCWs that disperse typically do not travel far, usually only a couple of miles to adjacent territories. Large dispersals of fifteen miles are rare. Dispersal distances are proportional to population density whereas dispersal distances decrease by the number of RCW groups encountered (McFarlane, 1992:142-144; USFWS, 2000:22). The lack of long-distance dispersal makes creation of new cavity clusters rare. New RCW groups in new cavity tree clusters form by two processes, pioneering and budding. Pioneering occurs when RCWs occupy vacant suitable habitat and construct new clusters. Budding, which occurs more often, happens when a group

splits its territory and cavity tree cluster into two separate groups. However, budding and pioneering rates are quite low with most new RCW groups forming in abandoned cluster sites (Walters et al., 1988:284-286; USFWS, 2000:19-20).

Reproduction and Parenting

RCW mating pairs breed typically once a year in March or April. Pairs may mate a second time in a season if initial nesting attempts fail. Nest failure rates average 20%. The clutch eggs are laid and nestlings are raised in the breeding males' nest cavity. The clutch is laid typically in April or May. RCW clutch sizes are usually two to four eggs. Incubation begins right after the clutch is completed. The white colored eggs hatch around the tenth day after being laid. Newly hatched nestling are almost brooded continuously for four days. The breeding pair and helpers feed the nestlings throughout the day. RCW nestlings are shown in Figure 4. Nestlings fledge around the 26th to 29th day after birth. A relatively new RCW male fledgling is shown in Figure 5. On average, 1.2 to 1.5 fledglings are produced per group depending on demographic location. The adults in the group will continue to feed fledglings for about six months after fledging. The success of raising young is increased with older breeding pairs and the presence of helpers (Ligon, 1970:265-271; USFWS, 2000:12-16).

Figure 4: Red-Cockaded Woodpecker Nestlings (Shaw, undated)

Figure 5: Red-Cockaded Woodpecker Male Fledgling (Shaw, undated)

Mortality

RCWs exhibit exceptionally high survival rates for a bird of its size. In general, female mortality is generally 10% to 15% higher than males. Fledgling survivor rates are approximately 50% for males and 40% for females (USFWS, 2000:16-17). The increased fledgling mortality rate is attributed to starvation (Ligon, 1970:274). However, helpers increase the number of fledglings produced in a group by approximately 25% (Reed and Walters, 1996:611; USFWS, 2000:15). Adults' annual survival rates average 80% for males and 70% for females in the entire RCW metapopulation. RCWs have lived up to sixteen years in the wild and seventeen years in captivity. However, there are not many elder birds past the age of ten. This is due to adult mortality mainly resulting from senescence (succumbing to old age). Dispersal also increases the chances of mortality, especially for females (USFWS, 2000:15-16).

Territorial Behavior

Despite their cooperative nature, RCWs are fierce defenders of their foraging territory against other RCW groups. Intraspecific conflicts occur usually between the home range boundaries of RCW groups. During these conflicts, RCW will give out adversarial calls, display their wings, peck at each other, and perform looping flights. The short-lived behavior terminates upon the retreat of the intruding or protecting birds (Ligon, 1970:262-262). Territorial interactions occur more frequently and form quite distinct home range boundaries in high-density RCW populations (McFarlane, 1992:157-159). RCWs defend only portions of their territory daily and take different foraging routes each day (USFWS, 2000:11). Also, territorial defense occurs more during the summer than any other season (DeLotelle and others, 1995:261-262).

RCW Nesting Habitat

RCW groups live in sets of cavity trees known as clusters. Typically, there is at least one cavity per adult (Bigony, 1991:13). Birds without cavities nest in clumps of dense tree branches or in pine tree crevasse scars. Some trees have multiple cavities. A cluster area, which contains all of the cluster's cavity trees, is approximately ten acres or more (Ligon, 1970:259; Hooper et al., 1980:2-3; Walters et al., 1988:276; USFWS, 2000:35). RCW prefer to excavate their cavities in old-growth pines. Cavity tree ages range from 80 to 150 years (Jackson and others, 1979:102; Hooper et al., 1980:6,8; USFWS, 2000:33). The preferred nesting tree is the longleaf pine. RCWs also nest in loblolly pine, slash pine, or other types of yellow pine (Lennartz et al., 1987:48; Bowman et al., 1995:415-416,426).

The reason that RCWs prefer older pines is that they offer more heartwood in the center of the tree to excavate their gourd-shaped cavity chambers (Bigony, 1991:13, USFWS, 2000:33). Also older pines have less sapwood around the outside trunk of the tree in which the RCW must bore through to get to the heartwood (Wahlenberg, 1946:5). RCWs do want to excavate cavities in high resin-flowing trees. Copious resin flow enables the RCW to protect its cavities from snake invasions. When the flow stops, RCW abandon the cavity (Ligon, 1970:260-261; Jackson, 1977a:449; McFarlane, 1992:86). Although the RCW wants trees with high sap resin flows, the sap itself is can be a problem. RCWs do not like to get the sap on their wings when going through the cavity entrance hole. Ironically, the sap flow that the RCW desires for protection from predators can trap RCWs inside their cavities due to sap buildup in the cavity hole passage (Bigony, 1991:14).

The presence of red heart fungus in older pines softens the heartwood and makes it easier for the RCW to chisel out a new cavity. Thus the RCWs prefer red heart infected pines for their cavities (Jackson, 1977b:160-162; Hooper, 1988:396-397). Exactly how the RCWs determine if a tree is infected is unknown, but a significant percentage of RCW cavity trees are infected (Ligon, 1970: 259-260; Rudolph and others, 1995:340-342). Construction of a longleaf pine cavity can take anywhere from one to nine years with the average being six years (Jackson et al., 1979:102-103; Conner et al., 1995:349). RCWs almost always excavate their cavities on the west side of trees. This is because the warming afternoon sun facilitates copious sap flow from resin wells that RCWs open prior to retiring to their cavities at night. The cavities are typically constructed just below the lowest limbs on the tree (McFarlane, 1992:76,101-103). RCWs typically devote segments of time each day to construction of new cavities. Construction occurs most often in the summer right after the fledglings have left their nests (Hooper et al., 1980:2). The completion rate of a cavity may be related to a RCW group's need for new cavities. The cavity completion rate for other pines is about half that of the longleaf pine. But still, the RCW prefers longleaf pine, nesting in them longer than any other pine (Conner et al., 1995:345). Longleaf pines are the most fire resistant pine, thus offering the greatest protection from wildfires (Wahlenberg, 1946:57). The nesting trees alone are not enough to provide overall optimum habitat. Suitable RCW habitat also includes adequate foraging habitat.

RCW Foraging Habitat

Foraging Trees. RCWs prefer to forage for insects on living pines. Also, RCWs sometimes forage on snags or hardwoods. Foraging pines are typically thirty years or

older with a dbh of 4 inches or larger (Skorupa and McFarlane, 1979:1-3; Hooper et al., 1980:3; Hooper and Lennartz, 1981:323). However, RCWs prefer to forage on larger pines because they offer more surface area for RCWs to travel upon in search of prey. Also, older pines have large bark scales that are easier to peck off and present better locations for prey to exist (Hooper, 1996:116). RCW have shown a preference to foraging on longleaf pines (Porter et al., 1986:245; Hooper, 1996:127; Hanula et al., 2000:60). RCWs differentiate foraging locations on trees due to gender. Male RCWs forage on the top and outer branches of trees whereas females forage on the trunk at lower heights on the tree. The difference has been theorized to occur because males, being the more dominant food providers, forage on areas that offer greater amounts of food (Ligon, 1968:206-212; Hooper et al., 1981:332-333).

Prey. The diet of the RCW is comprised mostly of insects with small amounts of plant fruit. The insect selection, primarily composed of arthropods such as ants and beetles, make up approximately 75% of the RCW diet. Segmented insects and flying insects cover about 10% of the RCW diet. The remainder of the RCW diet is composed of plant substrate such as fruit and seeds within their foraging area (Hanula and Franzreb, 1995:485-491; Hess and James, 1998:511-512; USFWS, 2000:41-42). RCWs will also eat cornworms from ripened green longleaf pine cones (Hooper et al., 1981:325). Insects make up a larger percentage of nestling diets than adult diets (Hess et al., 1998:511; USFWS, 2000:41). The quality of prey foraging habitat is not only dependent on the abundance of older trees, but also the quality of the understory vegetation. Most of the insect prey that RCWs consume is born on the forest floor vegetation. Insects commute daily back and forth between tree trunks and the forest floor. This relates the

importance of the understory to RCW habitat quality. (Hanula and Franzreb, 1998:99-101). Although frequent prescribed burns harm the understory insect communities, the relative abundance of insects is unchanged despite burn intervals (New and Hanula, 1998:182).

Hardwoods. RCWs tend to avoid tree stands dense in midstory hardwoods. The hardwoods choke out the pine seedling and saplings and can quickly dominate the lower stories of a tree stand (Martin and others, 1993:394-395). RCWs rarely forage on hardwoods and try to avoid them if possible (Hooper et al., 1981:331). RCWs like open park-like midstories within tree stands to allow for easy gliding in-between foraging pines and to their cavity entrances. Hardwoods clog up these pathways (Bigony, 1991:14; USFWS, 2000:47; McFarlane, 1992:164).

Fragmentation and Corridors. Fragmentation of RCW foraging habitat has been cited as a main factor in the species decline. The habitat-interior RCW is adversely affected when isolated to small ecosystem habitats caused by landscape fragmentation. Due to the RCW's sedentary nature, fragmentation makes RCWs susceptible to losses from a lack of demographic and genetic variation (Harris and Atkins, 1991:118-119). Not only does landscape fragmentation harm the RCW, but so too does fragmentation of habitat within a forest (McFarlane, 1992:165). It has been shown that fragmentation via timber harvesting near active clusters negatively affects RCW groups (Thomlinson, 1995:611; Rudolph and Conner, 1994:371; USFWS, 2000:7). Fragmentation limits the amount of foraging trees in the home range of RCW groups, but more importantly fragmentation disrupts dispersal routes between RCW groups (Rudolph et al., 1994:373). RCWs will disperse over large open areas only if they are forced to (McFarlane,

1992:165). Instead, RCWs prefer forest dispersal corridors when moving to other RCW clusters. Fragmentation cuts off available movement corridors from the RCW. The RCW dispersal mortality is relatively high because the birds are unable to find suitable habitat and RCW groups, often the result of inadequate corridors (USFWS, 2000:17). It is unclear what is the optimum amount of foraging habitat. However, there exists a level of timber harvesting that will cause RCW cluster abandonment (Beckett, 1974:7).

Home Range

The size of a RCW group's home range is dependent upon the quality, density, and type of foraging habitat along with their proximity to other RCW groups. RCWs spend the majority of their day foraging for food in their territories (Hooper et al., 1980:2). RCW home ranges are measured by using both the distance traveled and time used in search of food. Home range sizes have varied from 36 to 556 acres, averaging around 250 acres. Generally groups in large populations have smaller home ranges than groups in small populations because groups in large populations have to compete for the location's limited amount of foraging habitat. This results in territorial defense of foraging habitat by its RCW group (McFarlane, 1992:155-158). RCWs prefer old foraging trees in clusters that are closest in proximity to their cavity trees (Epting and others, 1995:274-276). Foraging ranges vary depending on the season and prey abundance. Foraging activities are driven by the ratio of amount of food acquired versus the energy used finding the food (Skorupa and McFarlane, 1979:1-3; Repasky and Doerr, 1991:46-49). Home range size also varies inversely with habitat quality (USFWS, 2000:48). For a bird of its size, the RCW requires an exceptionally large home range (McFarlane, 1992:160). The 2000 RCW recovery plan has used the concept of home

ranges to define the required foraging habitat that must be provided for RCW groups. For a high quality foraging site, 125 acres is defined as foraging habitat. In areas not of high foraging quality, 200 to 300 acres of foraging habitat is required. The plan also delineates what is quality foraging habitat by forest type (USFWS, 2000:155-157).

Predators

The RCW has few natural predators of severe consequence. Accipiters and other raptors have been reported to capture RCWs in flight, but the occurrence is rare (Ligon, 1970:274-275; McFarlane, 1992:62-63; Kulhavy, 1995:132). There are a few cavity-invading species that will prey upon RCW eggs and nestlings. It has been reported that southern flying squirrels (SFS) will eat RCW eggs and nestlings (Conner, 1995:337, Kulhavy, 1995:132, Montague et al., 1995:402). Tree climbing snakes such as the Rat Snake *(Elaphe obsolete)* sometimes can snatch RCW eggs and nestlings from cavities. RCWs, in an effort to combat snakes, bore out ancillary sap wells around the entrance to their cavity entrances. The punctures bleed sap down the tree in a process known as candling. The sap coating around the opening to the cavities provides a very effective barrier to snakes (Jackson, 1977a:448-449; Rudolph et al., 1990b:14,19). Snakes dislike the fresh sap getting in-between their scales, which causes limited movement (Bigony, 1991:14). As the resin holes dry up, a dead area is formed around the cavity entrance. Also, RCWs flake off the bark around the entrance to create what is known as the cavity plate. This plate makes the area around the cavity opening very slick, allowing little for a snake to grip. In addition, the candle-like resin flow from the wells is easily distinguishable and is thought to help the RCW identify cavity trees (McFarlane,

1992:85-86). The resin barrier defense is the reason for the RCW's low predation rate when compared to other cavity nesting birds (Rudolph et al., 1990b:14).

RCWs are more concerned with interspecies competition for their tree cavities. The main culprits that usurp (forcibly remove) RCWs from their cavities are Pileated Woodpeckers (*Dryocopus pileatus*), Red-Bellied Woodpeckers (*Melanerpes carolinus*), Red-Headed Woodpeckers (*M. erythrocephalus*), and the SFS (Rudolph et al., 1990a:31-34; Kappes et al., 1995:389-390). These species have been given the term "cavity kleptoparasites" (USFWS, 2000:56). Due to the small cavity holes, approximately two inches in diameter (Rudolph et al., 1990a:27), most cavity thieves are too large for the cavity entrance opening. In order to use RCW cavities, other woodpeckers have to enlarge them. This often occurs when the RCWs are out foraging. Defending cavities sometimes becomes a daily activity for the RCW (Ligon, 1970:262). RCWs typically abandon their cavities once they become enlarged due to old age or enlargement from other woodpeckers. Also, decreased resin well flow causes RCW cavity abandonment. The SFSs are mostly unaffected by resin coatings on cavity trees and often infiltrate un-enlarged RCW cavities (Rudolph et al., 1990a:31-32; Schaefer and Saenz, 1998:291-292). SFS have been shown to negatively impact the RCW reproductive success in some areas (Laves and Loeb, 1999:295). The amount of RCW cavity usurpation by kleptoparasites is most likely correlated to the local abundance of the kleptoparasites and available snags (Kappes et al., 1995:393).

Southern Flying Squirrels

Southern flying squirrels (SFS) are the main cavity competitors of the RCW. SFS occupy RCW cavities more than any other commandeering species (Rudolph et al.,

1990a:26; Conner et al., 1997a:13-14; Kappes et al., 1995:389). Woodpeckers that enlarge and take over RCW cavities are capable of excavating their own cavities in snags, whereas SFS are incapable of creating their own cavities and must use existing cavities and crevasses wherever found (Wells-Gosling, 1985:55-57; Kappes et al., 1995:389). It is unlikely that either the RCW or SFS could evict the other from a cavity (Rudolph et al., 1990a:33; Kappes et al., 1995:390).

The SFS is a unique avian rodent that inhabits practically the entire eastern half of the United States in all types of forest types. The mainly nocturnal rodent has a charcoal-gray short fur coat with cream-white breast fur and is 8-10 inches in length, weighing 2-4 ounces (Wells-Gosling, 1985:12-16, 66; Stone and others, 1997:110). The SFS glides at night by using its patagium, the extra skin attached from the front forearm to back leg's ankle. Pictures of SFSs are shown in Figures 6 and 7. When the SFS glides, it looks like a rectangular kite and can travel distances over 50 yards (Wells-Gosling, 1985:10-12, 73). The planimetric (planar) home range of the SFS has been estimated to be roughly 9.4 acres for females and 19.2 acres for males. SFS typically use five den sites

Figure 6: Southern Flying Squirrel (NGCP, 2001:n. pag.)

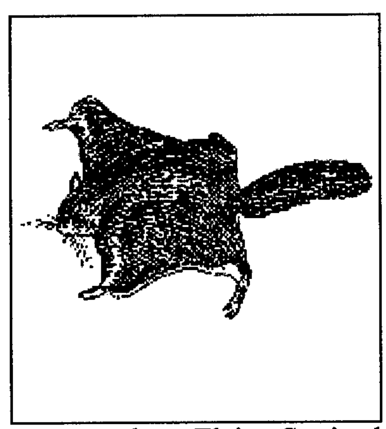

Figure 7: Southern Flying Squirrel Gliding (NGCP, 2001:n. pag.)

throughout their home range for sleeping, escaping, and feeding. Den sites include living and/or snag tree cavities, ground crevasses, twig nests, and nest boxes (Stone et al., 1997:106-110). Un-enlarged RCW cavities are high quality den sites that SFS seek out (Rudolph et al., 1990a:32). SFS move with ease from tree to tree and are not deterred by the open area between trees, thus suggesting removal of the understory around RCW cavity trees would not deter SFS (Loebb,1993:333).

The main diet of SFS in the southeast is roughly 75% hardwood nuts with the rest being other types of leaf and fruit substrate. Minor carnivorous behavior from SFS is displayed usually when food is sparse (Wells-Gosling, 1985:49, 78, 90-91; Harlow, 1990:187-189). Male SFS actively seek out females to mate with. The gestation period for a SFS is approximately 40 days with birth usually in April. Litter sizes range from one to five with an average of three. Female SFS are devoted mothers and solely responsible for raising and caring for their young (Wells-Gosling, 1985:24-29). Around twelve weeks, adolescent SFS become independent of their mothers. Depending on conditions, the mother may try to have another litter in the summer - breeding success and frequency increases with age (Wells-Gosling, 1985:24-29, 41-45). The SFS has a short life expectancy in the wild with the maximum around four to five years. SFS mortality is most often from predation followed by succumbing to the elements. The main predators of the SFS are owls, with additional predators being other raptors, snakes, canines, felines, and larger rodents (Wells-Gosling, 1985:60-62). Due to its large abundance, the SFS is one the most menacing interspecific competitors of the RCW.

Southern Pine Forest

The pre-settlement southern pine forests spanned the Atlantic and Gulf coastal plains from Virginia to Texas (Ware et al., 1993:450). The southern pine forests are classified into various types of communities that are composed of similar pine and/or hardwoods. In pre-settlement times, the dominant communities mainly were comprised of longleaf pine located in wiregrass savannahs, sandhills, flatwoods, and riparian ridge areas. The second most common communities were the transitional forests between the coastal plains and piedmont regions which are mostly comprised of longleaf pines and mixed hardwoods. Also included in these intermediary forests are loblolly, slash, and other pines (Ware et al., 1993:458). The traits and characteristics of the longleaf pine made it the keystone tree species that best adapted to the pre-settlement southern pine forests (Martin et al., 1993:390-398). Other communities include wetland coastal forests consisting of primarily slash pine and/or sand pine mixed with hardwoods (Little et al., 1954:3-4; Croker and Boyer, 1975:2; Martin et al., 1993:396). These community descriptions roughly depict the tree and topographic characteristics. Individual forests classified under this criterion have their own specific traits and conditions which make them each unique within their forest type community.

Today the southern pine forest breakout has drastically changed due to man's influences in fire suppression, off-site pine replanting, farming, and development (Frost, 1993:35). In the 1930s, the Civilian Conservation Corps along with other individuals and organizations reforested areas throughout the southeast with slash pine and loblolly pine (Schmidtling et al., 1998:1135). This was thought to be advantageous by foresters because longleaf pine did not grow as well as slash or loblolly pine in the sapling stage.

The faster-growing adolescent slash and loblolly pines' growth was stunted after initial growth in regions where conditions were not optimal for the trees (Hebb et al., 1975:6-8). The formally dominant longleaf pine communities make up about 3% of the southern pine forests as compared to 95% in pre-settlement times (Frost, 1993:17). Longleaf pines have given way to slash pines, loblolly pines and various hardwoods (Wahlenberg, 1946:1). The successional-mixed pine and hardwood forests dominate around 45% of the southern forests. The rest of today's southern forests are now comprised of harvested pine plantations, pastures, cropland, and developed areas (Ware et al., 1993:462).

A significant reason for the transformation to successional mixed pine-hardwood forests was fire suppression that southerners instituted around the beginning of the 20th century (Frost, 1993:35). The pine trees adapted to the natural recurring fires that controlled hardwoods in pre-settlement times. After fires, young pines sprout using the nourishing ashes left over by their hardwood competitors. Pines are able to persist with relatively frequent fires, which produces a pine-dominated, fire-maintained, sub-climax forest that continually short-circuits the successional process (McFarlane, 1992:21). With the suppression of wildfires, hardwoods were enabled to dominate the forest understory and choke out pine trees' seedlings and saplings. This natural succession of seral stages from pine trees to hardwoods was recognized in pre-settlement times around areas that naturally suppressed fires such as hydric wetland areas and geographically segregated areas (Martin et al., 1993:402). These successional forces that allow for hardwood encroachment were greatly strengthened by human influence and will dominate the southern pine forests with further fire suppression practices.

Longleaf Pine

The native range of the longleaf pine includes most types of the southern pine forests of the southeastern United States (Wakely, 1935:2-3; Frost, 1993:17-18; Boyer, 2000:n. pag.). Longleaf pines grow in a variety of site demographics from wetland or sandy flatwood soils to rocky dry piedmont areas (Boyer et al., 1983:153). Longleaf pines grow best on well-drained, sandy, acidic soils that are low in fertile organic matter, calcium, and nitrogen (Wahlenberg, 1946:52). The longleaf pine is a long-lived conifer that has reached ages up to 500 years (Platt and others, 1988:511). Since longleaf pine forests are occasionally exposed to tropical storms and intense wildfires, seldom do they reach their biological potential (Landers et al., 1995:39).

The longleaf pine is an intolerant pioneering species limited by seed dispersal that will only spread into open areas caused from windblown trees or wildfires (Boyer et al., 1983: 153). The longleaf pine has adapted well to the southern forest environment being very resistant to fire, insect, and ice damage (Wahlenberg, 1946:56; Boyer, 2000:n. pag.). Fires naturally created a mosaic of park-like even-aged stands of longleaf pines throughout the southeastern forests. Longleaf pine produces its own fire-fuel in the form of needles and fallen lower limbs. Amount of fuel depends on the periods between burning (Wahlenberg, 1946:57, 154-155).

Longleaf pine has many commercial uses for its pulpwood and pole timber. The high quality hard-pine longleaf lumber is desired for construction use. Living longleaf pines are used by the naval industry for turpentine production (Wakely, 1935:2; Wahlenberg, 1946:16). Longleaf pine prices are approximately \$4.30/ton for pulpwood timber and \$30.85/ton for saw timber. Longleaf pine straw is sought after for its

excellent mulching capability. Current prices for longleaf needles are $0.75/bale (Early, 1997:27).

Longleaf pines are a monoecious tree in that it possesses both male and female reproductive organs on different parts of the same tree. The different organs reproductive processes, which are triggered by different climatic conditions, do not always coincide (Boyer, 2000:n. pag.). With the complexity of seed development, the longleaf is a poor seed producer compared to other pines (Wahlenberg, 1946:4; Boyer et al., 1983:153). Good crops of pinecones occur about every five to seven years with crop failures occurring around every one to five years (Boyer, 1986:73). Longleaf pines start producing seeds around their late-sapling stage to early pole timber stage. The quality of seed is about the same for young and old longleaf pines (Wahlenberg, 1946:70-71). The best producing longleaf pines are open-growth longleaf pines with large crowns and dbh's of 15 to 19 inches (Wahlenberg, 1946:75-77; Boyer, 2000:n. pag.). The amount of seeds in the cones is dependent on the growing season conditions and ranges from 15 to 50 seeds per cone with an average of 35 (Croker et al., 1975:4). For optimal natural regeneration, 750 to 1,000 pinecones per acre are needed annually which will correlate to approximately 6,000 seedlings per acre (Boyer et al., 1983:155).

The longleaf cones are serotinous in that they remain sealed by resin coating. The cones release their seed once the seal naturally wears off or melted off upon exposure to heat from fire (Wade and others, 1980:163:95; Platt et al., 1988:516-517). Longleaf pine cones are relatively large in comparison to other pines, six to ten inches in length. The cones are cylinder-shaped unopened and egg-shaped when opened (Harlow and Harrar, 1941:81-82). Upon release from the pinecone, seeds disperse in the wind via their small

wings and germinate soon after as long as soil conditions are favorable (Wahlenberg, 1946:5; Boyer, 2000:n. pag.). The seeds need to make contact with soil minerals and have adequate moisture; conditions which are produced after a fire (Boyer et al., 1983:154).

After germination, the seed quickly grows its taproot downward to secure itself into the topsoil (Boyer, 2000:n. pag.). Once the taproot is established, the seedling grows an extensive lateral root system just below the soil to claim the available nutrient pool in its immediate vicinity (Wahlenberg, 1946:94-97). The new seedlings above ground are grass-like plumes. The seedlings' main concerns at this time are intraspecific root competition with its parent tree and other seedlings as well as brown-spot blight needle disease (*Scirrhia acicola*). Seedlings that are in burned areas, higher densities, and/or close to parent trees are less susceptible to the disease (Wahlenberg, 1946:108; Boyer et al., 1983:154). The majority of seedlings do not survive the first few years due to drought, animal consumption, logging, and fire (Wahlenberg, 1946, 81; Boyer, 2000:n. pag.).

Seedlings exist in this grass stage usually four to five years but may last up to twenty years if its growth is stunted. Figure 8 shows a seedling in the grass stage. The seedling is vulnerable to fire in its first few years but soon develops a relatively insulated terminal growth bulb (Wahlenberg, 1946:88, 163; Croker et al., 1975:5; Martin et al., 1993:392). Once an opening in the overstory occurs due to falling of a mature tree, the seedling is signaled by the increased sunlight to start growing its main stem. In the next couple of years, the main stem shoots up from the seedling in trying to gain as much height as possible. The purpose of the rapid growth is to avoid fire damage by raising the

growth bulb atop the main stem (Wahlenberg, 1946:151-152; Platt et al., 1988:498). As long as the growth bulb is unburned, the seedling main stem will survive. Once seedlings grow above three feet in height, they are relatively safe from small fires. The optimal natural regeneration for seedlings is about 500 well distributed, three feet or taller, seedlings per acre (Wahlenberg, 1946:147; Croker et al., 1975:6, 15). At this point, the longleaf seedling is now considered a sapling, shown in Figure 9.

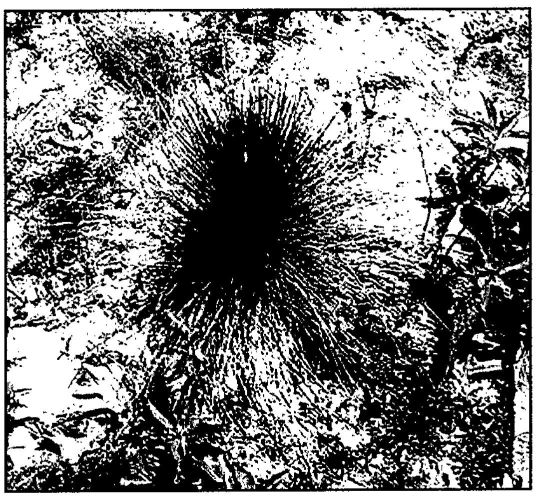

Figure 8: Longleaf Pine Seedling (Schroeder [at Shaw], 2000)

Figure 9: Longleaf Pine Saplings (Schroeder [at Shaw], 2000)

The sapling and pole stages are the next sequential growth phase to maturity for the longleaf pine ranging between five and twenty years of age. Longleaf pines at twenty years of age are typically 25 feet tall with a five-inch dbh (Wahlenberg, 1946:215; Platt et al., 1988:498). The longleaf pine's reputation as a slow-growing tree may not be deserved (Boyer et al., 1983:154). Longleaf pines get this reputation due to their relative slow growth in the seedling stage. Given optimal conditions, the longleaf can grow as well if not better than other pines of the same age (Boyer, 2000:n. pag.). The site variables play a major role in the growth rate of longleaf pines. Relevant variables

include stand tree density for different age classes; site condition factors such as soil type, seed source, and climate; and site quality which pertains to understory growth and fire frequency (Boyer, 1983:19-21). On average, longleaf pines grow about 2 feet per year up until about age fifty. Longleaf pines at this age are approximately 60 feet tall with a 10-inch dbh. The growth rate gradually drops after age fifty. The longleaf meets its maturity stage around the age of one hundred years where they are approximately 85 feet tall with an 18-inch dbh (Wahlenberg, 1946:215; Platt et al., 1988:498). Figures 10 and 11 show old-growth longleaf pines.

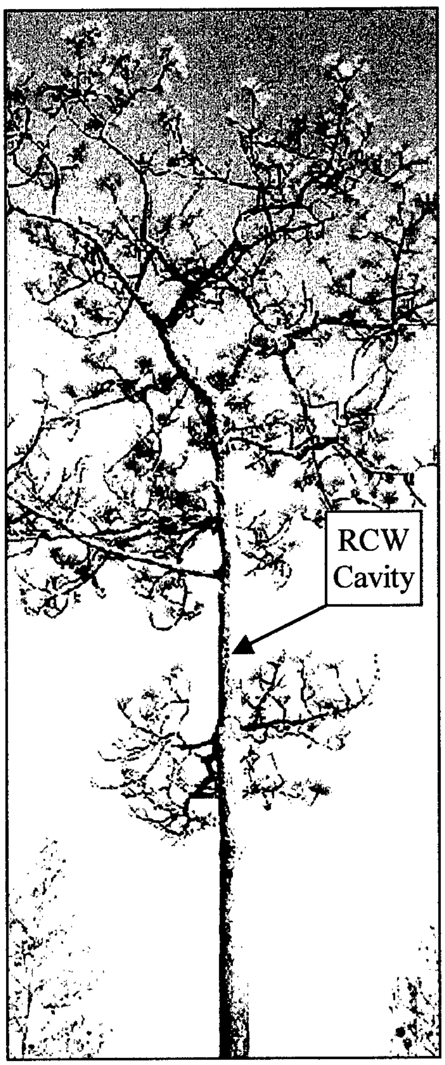

Figure 10: Longleaf Pine with Cavity (Schroeder [at Eglin], 2000)

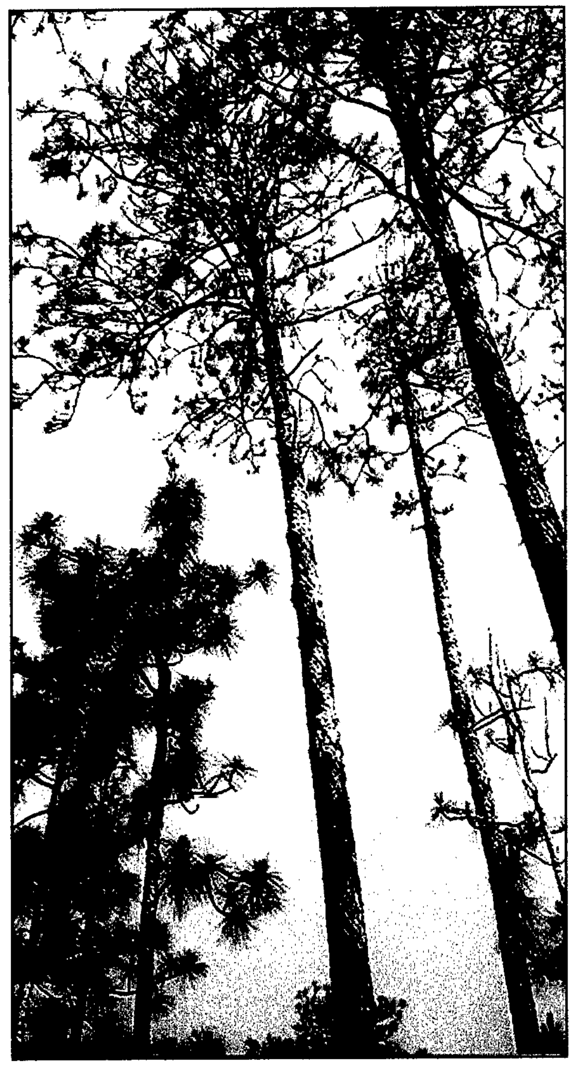

Figure 11: Longleaf Pines (Schroeder [at Shaw], 2000)

Mature longleaf pine death is usually initiated by damage from lightning strikes, storm winds, or severe wildfire (Boyer, 2000:n. pag.). Red heart fungus disease attacks the heartwood of mature longleaf pines. This softens the heartwood of the longleaf – the preferred condition that RCWs desire when excavating cavities (Beland, 1971:125; Jackson, 1977b:160). The creation of a cavity by RCWs decreases the life expectancy of mature longleaf pines (Hooper and Kulhavey, 1995:145). The increased mortality is due to the longleaf pines being more susceptible to the debilitating conditions brought on by red heart infection. Also mortality rises due to wind damaged resulting from the weakened trunk cross-sectional area at the cavity (Hooper, 1995:162). Once damaged, mature longleaf pines become susceptible to beetle infestation (McFarlane, 1992:169; Conner et al., 1995:352). The southern pine beetle (*Dendroctonus frontalis Zimmermann*) (SPB) is the primary insect that attacks longleaf pine and other southern pines. Though longleaf resin is a great SPB deterrent (Wahlenberg, 1946:187), SPB outbreaks can fatally wound large numbers of RCW cavity trees (Conner et al., 1997b:145-148). Annual cavity tree mortality ranges from 4% to 9% (Hooper et al., 1980:2). Shaw AFB's Poinsett Weapons Range (PWR) experienced a SPB breakout in Area 8 (refer to Appendix A map) during the early 1990s, which destroyed approximately 50 acres of longleaf pines including six cavity trees (Shaw, 1996:52).

Slash Pine

Slash pine has many of the same southern pine characteristics that the longleaf pine possesses. The native range of the slash pine covers all of Florida and includes the coastal plain areas from eastern Louisiana to southern South Carolina (Wakely, 1935:2; Lohrey and Kossuth, 2000:n. pag.). There are two common variations of the slash pine.

P. elliottii var. elliottii (termed "typical") exists in the northern slash pine range and *P. elliottii var. densa* (termed "Florida") only exists in southern Florida and the Keys (Little et al., 1954:1-2). Slash pine plantations have been introduced in non-native areas of the southeast as far north as Tennessee (Harlow et al., 1941:93; Lohrey et al., 2000:n. pag.). The reason for the replanting with slash pine is its frequent and abundant seed production and initial early growth (Wakely, 1935:66-67; Lohrey et al., 2000:n. pag.). Slash pines however require well-drained, yet moisture-retaining silt loam soils. If not well-drained, then fusiform rust disease (*Cronartium Forimost Hedg. And Hunt*) forms on the roots which retards the slash pine's growth. Conversely, if enough moisture is not retained, then the slash pine's growth is stunted (Hebb et al., 1975:2, 5-6; Cain, 1978:2, 6). Slash pine has the similar longleaf commercial uses for its pulpwood and pole timber. Grown in its native range, slash pine displays excellent growth and is an ideal tree for pine plantations that use thirty-year harvest rotations. Slash pines are also worked by the naval industry for resin and turpentine production (Wakely, 1935:2, 6; Lohrey et al., 2000:n. pag.). Timber prices for slash pine are approximately same as longleaf pine.

The seedling dispersal, germination, and growth of the slash pines are faster than the longleaf pines. These traits enabled the slash pine seedlings to out-compete the longleaf pine seedlings in moist-soil flatland settings (Harlow et al., 1941:93-94). Though not as resistant as the longleaf pine, the slash pine possesses the longleaf's fire resistivity characteristics (Wade et al., 1980:99, Landers and Boyer, 1999:3). Older slash pines in their native area exhibit the similar size and growth characteristics of the longleaf pine (Harlow et al., 1941:93-94; Lohrey et al., 2000:n. pag.). A stand of slash pines is shown in Figure 12. Older slash pines are capable of supporting RCW cavities. In

forests devoid of longleaf pines, such as in southern Florida, RCW excavate their cavities in slash pine (Bowman et al., 1995:415-416). Slash pines are also susceptible to SPB attacks, but are highly resistant, similar to longleaf pines (McFarlane, 1992:175).

Figure 12: Slash Pines (USDA, 2001:n. pag.)

Other Pines

The southern pine forests also contain other types of pines that are associated with the longleaf pine and slash pine. Loblolly pines are found throughout the southeastern southern pine forests. Similar to the slash pine, the loblolly pine requires moist soils to grow well. The loblolly pine is considered the most tolerant of all the southern pines when faced with hardwood encroachment. This trait has allowed the loblolly pine to

spread quite remarkably. The shortleaf pine is found primarily in regions of the southern pine forests that contain dry upland soils. The shortleaf pine has the unique ability to resprout upon main stem damage from fire. (Harlow et al., 1941:86-88, 90). A common problem with the loblolly pine and shortleaf pine is their susceptibility to SPB attacks (McFarlane, 1992:175; Conner et al., 1997b:148). Pond and sand pines are found in the coastal plain forest areas. These two pine types are not as large as the other southern pines (Harlow et al., 1941:94-96). All of these associate pines located with the longleaf and slash pines can support RCW cavities. Still given the choice, RCWs prefer longleaf pines over all the others (Lennartz et al., 1983:48; Bowman et al., 1995:415-416,426).

Hardwoods

Throughout parts of the understory of southern pine forests are hardwood trees (Landers et al., 1999:3). The dominant hardwood in the sandhills region of the PWR is the turkey oak (*Quercus laevis Michx*). The turkey oak dominates because its bark is fairly fire resistive and it has the ability to resprout quickly after a fire. Also, the turkey oak has multiple sprouts from one root system (McGinty and Christy, 1977:490; Moser, 1989:60). Figure 13 shows how turkey oaks can dominate the forest understory. Turkey oaks can reach heights of 60 feet, yet are usually 20 feet tall (Sargent, 1965:253). On the PWR, turkey oaks typically have an average dbh of 4 inches. Mortality by fire decreases inversely to dbh growth (Moser, 1989:66). Turkey oaks have little mercantile value except for fire wood use and are often considered a forest weed (Wahlenberg, 1942:248). However, turkey oaks do provide an acorn food benefit to forest wildlife such as the SFS.

Figure 13: Turkey Oaks at the Base of Longleaf Pines (Schroeder [at Shaw], 2000)

Snags

Snags, standing dead trees, are caused by a number of conditions including lightening strikes, wind damage, beetle infestation, and various diseases. Snags play an important part in the functioning of an ecosystem by providing shelter for a number of species (Everhart and others, 1993:38; Kappes et al., 1995:389). Among these species are ones that will usurp RCW cavities if snags are not available. Therefore, it is thought that if there are fewer snags available that cavity-dwelling species will seek out RCW cavities in live pine trees. However, another argument states that cavity dwelling species will not inhabit cavity barren areas. Traditionally, southern pine forests have policed snags by falling them in wildfires (Ligon, 1970:261). Also, forestry practices have followed the practice of removing snags due to their prevalence for attracting beetles and spreading disease (McFarlane, 1992:188; Everhart et al., 1993:38). The presence of snags presents a circular debate in regard to their impact on RCWs. Snags in one sense relieve the pressure of kleptoparasitism by providing homes for cavity competing species (Kappes et al., 1995:393). However, the existence of snags may attract more of the

cavity-dwelling species. However, if given the option, cavity-usurping species select RCW cavities over snag cavities. This argument negates the effect that snags would have on relieving kleptoparasitism (Everhart et al., 1993:42).

RCW Management

The proper management for the RCW is quite extensive but at the same time measurable and effective. Management incorporates care for the RCWs themselves and their habitat. The 2000 RCW recovery plan prescribes specific habitat requirements for RCWs (USFWS, 2000:103-106,154-159). The management of the RCWs southern pine forest habitat often involves returning the ecosystem to its natural fire-culture process (USFWS, 2000:98-103). Proactive techniques in the recovery plan involve direct RCW management through monitoring RCW populations and providing optimal nesting and roosting tree cavities. Intensive management practices also include translocating birds to augment small populations (USFWS, 2000:64-88). If the RCW is to be removed from the US endangered species list, it will need help through proper management. The bare minimum requires complying with the habitat requirements in the recovery plan. Proactive techniques are needed to save small isolated populations. The long-term goal is to return the RCW populations in the southeastern United States to stable self-sustainable levels (USFWS, 2000:126). Renowned RCW researcher Jerome Jackson dually notes that along the road to RCW recovery, we do not want to go so far with our management techniques in that we create a "bionic woodpecker population" (Jackson, 1995:48).

Forest Management Techniques

Management of the RCW encompasses short and long-term goals that are either required by law or highly encouraged. Short-term management goals are designed to

preserve and protect the RCW and its habitat from extirpation, local extinction. Long-term goals are planned to create sustainable conditions for the entire RCW metapopulation and its habitat. The USFWS, which executes the ESA, lays out the minimum requirements that must be met on federal lands containing RCWs. Additionally, there are many intensive measures, not required by law, that can implemented to aid in the recovery of the RCW.

Prescribed Burning. Prescribed burns are used to simulate the once recurrent natural wildfires that were common in pre-European forests in the southeastern United States. Fires were ignited by lightening strikes; also Native Americans set forests afire to clear land and drive game for hunting (Frost, 1993:21; Ware et al., 1993:456). The prevention of forest fires starting in the late 1800s reduced the conditions that the longleaf pine forests adapted to (Frost, 1993:34-35). In turn, accumulation from forest debris provides fuel for ravenous wildfires. Prescribed burns are designed to clear out the forest understory of debris, kill off hardwoods, return nutrients to the soil, and spur the growth of fire-adapted pines (Hermann and others, 1998:384; USFWS, 2000:94-95). The preferred burn schedule is to burn an area on a three to five year rotation. The schedule prevents the accumulation of debris that fuels destructive wildfires. Figures 14 and 15 show what prescribed burns look like. Burning is usually done in the fall/winter timeframe in which the conditions are optimal to control the fire (Hermann et al., 1998:387-388; McNabb, undated:4). Prescribed burning is generally considered to be a necessary management method for RCW habitat (USFWS, 2000:94).

Figure 14: Prescribed Burn Lighting
(Ft. Jackson, 1999:n. pag.)

Figure 15: Prescribed Burning
(Shaw, undated)

Fires keep the hardwood growth under control, but suppression of fires can quickly lead to hardwood forest domination (Martin et al., 1993:394-395). Hardwood encroachment is a major reason for the loss of suitable habitat for RCWs. If not controlled, fast-growing hardwoods choke out the understory of pine seedlings and saplings (Moser, 1989:60-61). Larger hardwoods fill up the forest midstory, the space that RCWs freely swoop through and construct cavities. The invasion of hardwood branches in the midstory dissuades RCWs, even if there are old-growth pines in the area (Bigony, 1991:14). Prescribed burns are the main method used to control hardwood encroachment. Despite the burns, hardwood saplings sprout up in burnt areas in the next growing season. In addition, larger burnt hardwoods resprout after a fire leading to an even higher hardwood density than before. To overcome this problem, successive burns need to be applied on a rotating basis (every two to three years). Once hardwoods are brought under control, then burning frequencies can lengthen to every three to seven years (Wade et al., 1980:109).

Herbicide Use. Another way to control hardwoods is using herbicides on older trees. Hexazinone is a preferred herbicide approved for forestry use in the United States (Brockway et al., 1998:163). Herbicides can be applied by: spraying the trees leaves and stems through which the herbicide is absorbed; spraying the tree base through which the roots absorb the herbicide, or slashing the hardwood's trunk to expose xylem tissue in which the herbicide is injected (Campbell and Long, 2000, n. pag.). Herbicides are quite effective in killing hardwoods and preventing their regeneration (Brockway et al., 1998:171-172). Also, hardwoods can be mechanically removed. Herbicide application and mechanical removal followed by prescribed burning is more effective in controlling hardwood encroachment than prescribed burning alone. However, herbicide application and mechanical removal are often more time and resource intensive and can have possible adverse residual affects (Brockway et al., 1998:171, USFWS, 2000:101-102).

Silviculture. Stephen Boyce, a prominent forest ecologist, defines silviculture as, "The use of knowledge and technology to direct the behavior of the self-organizing, individualistic systems that make up a forest. The directing actions or culture practices are designed to guide the ecosystem and order the forest to produce biologically possible and desired results," (Boyce, 1985:81). Silviculture management uses three controls: conversion of forest species and age classes, rates of timber harvests, and sizes of opening formed by harvesting. A forest is in a steady-state when the distribution of stands by forest type, age, and area classes is constant (Boyce, 1985:82-84; Landers et al., 1999:9). This steady-state is known as a climax stage (Hamel and Buckner, 1998:310). In untouched forests, steady-state climaxes are achieved then change due to differing regeneration and harvesting rates along with impacts of natural disturbances. Silviculture

may enable forests to progress to their climax state quicker. The amounts, sizes, and rates of silviculture harvests are determined by the experience and knowledge of forest managers as they seek to reach a desired steady-state that meets specific goals. These goals may include optimal sustainable timber production, habitat creation/alteration, and/or modifications for recreational use (Boyce, 1985:84). Goals may often conflict between the logging industry and providing optimal RCW habitat. The logging industry wants to harvest longleaf before the onset of red heart infection that rots the wood. (Jackson, 1994:159). A pioneer in RCW research, Dan Lay stated that, "Modern silviculture is based on getting you money as early and as fast as you can before something happens. The longer you leave a tree out there, the more risk you have for insect damage or lightening damage" (Bigony, 1994:14). A debate exists in what type of silviculture practices should be used for RCW management. The two silviculture theories for RCW management are uneven-aged and even-aged.

Uneven-age. Under uneven-age silviculture management, trees of various ages or size classes are retained throughout stands. To maintain the ideal class densities, thinnings are required every five to ten years (Walker, 1995:115; Engstrom and others, 1996:336; Hedrick and others, 1998:145). The main advantage to uneven-aged management is that foraging habitat and potential nesting trees are kept at the same level (Engstrom et al., 1996:336). Also, uneven-aged management gives a certain aesthetic appeal of a natural forest that is taken away with even-aged harvests. Uneven-aged management has its critics. First, controlled burns are not as effective and even harmful due to susceptible seedlings existing at all times (Rudolph and Conner, 1996:332). Second, pines grow better in direct sunlight; therefore older trees continually hinder the

growth of younger trees (Wahlenberg, 1946:5; Hedrick et al., 1996:141). Third, uneven-aged management requires continual removal of trees. Thus labor demands are greater along with the potential to damage trees left standing after thinnings (Rudolph et al., 1996: 332; Hedrick et al., 1998:142). There are no definitive examples of RCW populations thriving under uneven-aged silviculture management (Hedrick et al., 1998:145).

Even-Age. Under even-aged management, otherwise known as shelterwood, a large proportion of trees in an area are cut, leaving behind a substantial amount of residual seedtrees. These seedtrees disperse their pinecones over the newly harvested area, which in turn will produce an even-aged stand of trees. An example of a shelterwood cut is shown in Figure 16. Once the new seedlings establish themselves and begin to grow their main stems, the seedtrees are harvested to allow for maximum seedling growth and nutrient uptake from the soil. Irregular shelterwood (two-aged) is the practice in which the remnant trees are left to grow with the new seedlings (Rudolph et al., 1996:331). Both shelterwood methods are instituted under rotational periods over 80 years depending on tree composition and management goals (Walker, 1995:112-113).

Figure 16: Shelterwood Cut (Canfor, 2001:n. pag.)

There are arguments for even-aged shelterwood rotational management. First, even-aged management allows for prescribed burns to be performed at optimal times in which the burn would not hurt susceptible seedlings. Second, management and labor requirements are low as is the disturbance to the ecosystem in respect to the entire rotation cycle (Rudolph et al., 1996:331-332). Third, it has been shown that even-aged silviculture methods produce the most potential RCW cavity trees per acre than any other method (Walker, 1995:121). National forests incorporating even-aged management have grown their RCW populations, some to recovery levels. The disadvantages of even-aged management are that the seedtrees left after initial harvests are susceptible to lightning strikes and wind damage. Also RCWs may be forced to move their colonies due to inadequate nesting and foraging habitat after initial harvest (Engstrom et al., 1996:336; Hedrick et al., 1998:145).

Conversion. Another form of even-aged management is the conversion of tree types. The difference with conversion is that a site first needs to be clear-cut of the original trees and then replanted with a different type of tree. In the reforestation efforts of the 1900s, slash pines were planted in clear-cut areas throughout the southeastern United States (Wakely, 1935:6; Row, 1960:704; Frost, 1993:36; Ware et al., 1993:465). The slash pine exhibits faster initial growth than longleaf pine (Wahlenberg, 1946:139). But some of the introduction plans for the slash pine did not take into account of the soil type. Slash pine grows well in moist hydric soils found in Florida and the lower coastal Gulf and Atlantic plain regions. However, slash pine does not fair as well in sandy xeric soils in sandhill regions. Thus, the converted slash pine stands often exhibited stunted older growth after initial growth (Row, 1960:704-707; Hebb et al., 1975:5-6; Cain,

1978:6). Also, off-site pines often have higher mortality rates from fires (Hermann et al., 1998:387). A recent movement in the forestry management is to restore (convert) current off-site slash pine stands back to longleaf pines. Conversion is costly and labor intensive due to acquiring and planting high-demand longleaf pine seedlings. In the long run, slash pine to longleaf pine conversion will greatly benefit the RCW by providing the best possible habitat (Beyer et al., 1996:827; Engstrom et al., 1996:334). Figure 17 shows an area that underwent conversion to longleaf pines.

Figure 17: Planted Longleaf Pine (Ft. Jackson, 1999:n. pag.)

Cavity Competitor Deterrence

Restricto Plate. A popular deterrent against RCW cavity-enlargering woodpeckers are cavity hole restrictor plates. Restrictor plates are brown-painted aluminum flashings with a downward facing U-shaped opening, 2 inches in diameter that are aligned over the cavity hole. The plates are thick enough to prevent bending by woodpeckers and are nailed or screwed to the tree. The U-shape allows for RCWs to

perch on the bottom of the hole before they enter their cavities. Restrictor plates are effective in reducing usurpation and preventing cavity enlargement from other woodpeckers (Carter et al., 1989:69-70; Saenz and others, 1998:365). Cavities installed with restrictor plates do not dissuade use by RCWs (Carter et al., 1989:70; Watson and others, 1995: 177). Researchers caution that restrictor plates are not a panacea for RCW management, but should be used to complement other management practices. Also, restrictor plates may weaken RCW beaks from pecking on the plates and require expert labor-intensive installation and maintenance (Carter et al., 1989:70-71). Figure 18 shows a sketch of a restrictor plate installed over a cavity entrance hole.

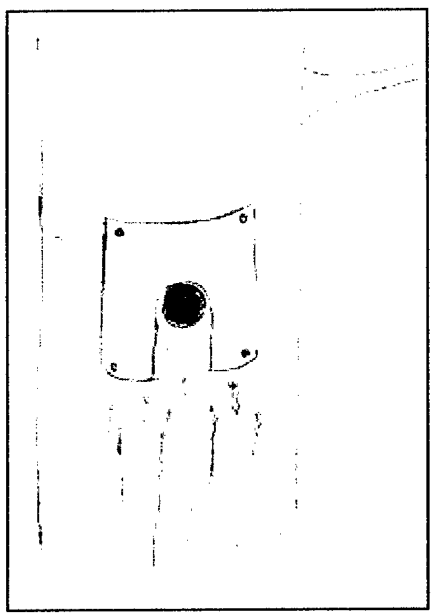

Figure 18: Restrictor Plate

SNED. The resin barrier that RCWs create often prevents snakes from climbing trees, but some snakes can navigate through the dry parts of the barrier (Rudolph et al., 1990b:19, McFarlane, 1992:89). Snake Excluder Devices (SNEDs) are used to deter snakes from climbing RCW cavity trees. A SNED is a 25-inch wide aluminum sheet that

is fixed with heavy-duty staples around the base of a cavity tree at breast height. SNEDs have been shown to significantly impede snakes tree-climbing ability. Smaller snakes are more adept to climbing than larger snakes. However, neither is able to pass a SNED (Whitgott et al., 1995:394-397). As with restrictor plates, SNEDs require intensive labor and maintenance to be effective. While RCWs have a relatively low nest predation rate, any loss of eggs and/or nestlings can lead to local extirpation of the endangered birds (Rudolph et al., 1990b:20). Figure 19 shows a sketch of a SNED deterring a snake.

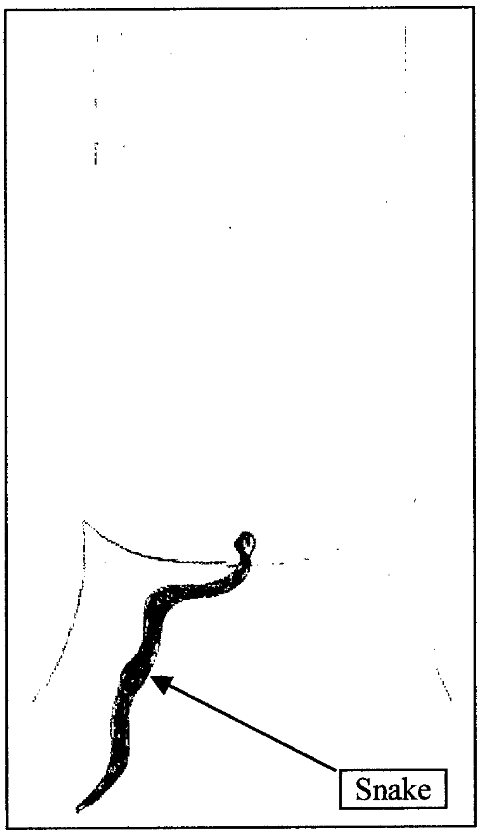

Figure 19: Snake Excluder Device

SQED. Squirrel Excluder Devices (SQEDs) were developed to restrict SFS from entering RCW cavities. SQEDs are simply two bands of aluminum flashings, around 2

feet in width that are attached to a tree with heavy-duty stapling. The bands are approximately 3 inches above and below the cavity entrances with the tops of the flashing bent at a 90° angle (Montague et al., 1995:401; Loeb, 1996:305). The flashings are bent to collect sap from flowing on the bands, thus preventing the creation of a path for the SFS to climb on. Figure 20 shows how SQEDs are installed around a cavity. When mounted, SQEDs have shown significant results in restricting SFS from entering RCW cavities. Also, cavity trees with SQEDs have been reoccupied by RCWs once SFS evacuated the cavities. The only way that SFS have been able to get around the SQEDs is to glide directly to the cavity opening from nearby adjacent trees (Montague et al., 1995:404-408, Loeb, 1996:307-308). Like the other deterrence devices attached to trees, SQEDs require the proper installation and maintenance to be effective.

Figure 20: Squirrel Excluder Device (SRS, 2000:n. pag.)

Nest Box. Nest boxes provide an alternative shelter to other species that compete for RCW cavities. The nest boxes are attached to trees within RCW nesting habitat, anywhere from 20 to 50 yards from RCW cavity trees. Figure 21 shows an installed nest box. SFS and other birds are the main occupiers of the nest boxes. Although nest boxes may not lower other species' use of RCW cavities, their presence has correlated to higher nestling and fledgling rates (Loeb and Hooper, 1997:1269-1278). However, the existence of nest boxes may bring in even more cavity competitors than normal. Nest boxes have also been used as traps to catch SFS for removal and even extermination (Franzreb, 1997:460).

Figure 21: Nest Box (Archbold, 2001:n. pag.)

Artificial Cavities

Use of artificial cavities has proven to be an effective way to promote RCW occupation of unoccupied suitable habitat and create new RCW groups (Krusac et al., 1995:62, Carter and others, 1995:379, Walters et al., 1995b:367). The presence of

cavities is viewed as the most important component of RCW clusters (Ligon, 1970:258-259). RCWs prefer to disperse towards existing habitat clusters instead of cavity vacant habitats (Walters et al., 1988:301). Therefore, in order to increase RCW populations via new group creation, new cavity-laden habitats should be provided (Walters et al., 1995a:384). Artificial cavity creation is much quicker and effective in providing new cavities instead of natural expansion (Gaines and others, 1995:83-84). This effective technique should be used as a short-term technique to create new RCW cluster areas (Bigony, 1991:17; Carter et al., 1995:379). Additional cavities within the new clusters should be left to natural RCW cavity excavation for the long-term sustainment of the species (Jackson, 1995:47-48).

Drilling. Copeyon developed a specific drilling technique to create artificial RCW cavities (Copeyon, 1990:303). Complete or partial cavities can be created with drilling. Partial cavities, which are quick to construct, consist of just drilling a hole upwards toward the interior of the tree to create the cavity entryway. Full cavities include the drilling of a upward-slanting horizontal entry hole with the drilling of an additional hole downward above the entry hole. Through the vertical hole, the cavity chamber is bored out inside the heartwood. The vertically drilled hole, which intersects the entry hole in the tree's heartwood, is plugged up upon completion of the cavity. Though not all cavities are used or completed in the case of partial cavities, they are an effective short-term method to grow RCW populations (Copeyon, 1990:307-309; Walters et al., 1995a:382-384). Figure 22 shows the initial drilling an artificial cavity's entry passage hole.

Figure 22: Artificial Cavity Drilling (Shaw, undated)

Artificial Cavity Insert. Artificial cavity inserts, developed by Allen, have been the most effective artificial cavity creation technique (Krusac et al., 1995:61; Gaines et al., 1995:81). The inserts are rectangular birdhouses that are installed into a compatible cut made approximately 18-24 feet high in the tree's trunk. An artificial cavity cut is shown in Figure 23 and an installed insert is shown in Figure 24. Inserts can be used in younger trees with sapwood less than 3.5 inches, the requirement for artificial cavity drilling (Allen, 1991:1-2; Richardson and Stockie, 1995:99). Cavity box inserts have

Figure 23: Artificial Cavity Box Cut (Shaw, undated)

Figure 24: Artificial Cavity Box Installed (Shaw, undated)

demonstrated their effectiveness by the success in the recovery of the RCW population on the Francis Marion National Forest after Hurricane Hugo in 1989. Also cavity box inserts were the critical tools that helped recover the nearly extirpated RCW population at the Department of Energy's Savannah River Plant Site (Watson et al., 1995:172; Franzreb, 1997:458).

Direct RCW Management

Monitoring. The Air Force requires that current inventories be kept on endangered and threatened species through population monitoring programs (DAF, 1997:13). RCWs are extremely suitable to monitoring programs due to their non-migratory nature. Accurate counts of RCWs are made possible through a banding identification program. Capture and then banding of adult birds is done by flushing them from their cavities into nets. Once the adult population is banded, managers then only need to band new nestling broods. A recently banded brood of RCW nestlings is shown in Figure 25. Only wildlife managers with permits from the USFWS can independently

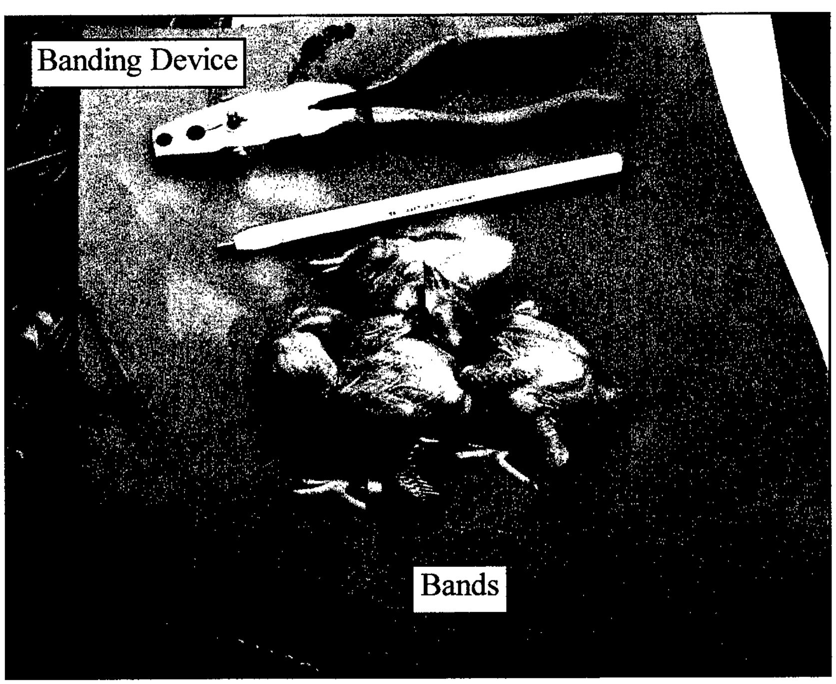

Figure 25: Red-Cockaded Woodpecker Banding (Shaw, undated)

handle and band RCWs (USFWS, 2000:226-229). Geographic Information Systems (GIS) are used to incorporate RCW monitoring data into a geographic database of forest systems. This capability provides a useful tool in developing alternate RCW and forest management strategy scenarios (Lipscomb and Williams, 1995:137).

Translocations. Translocation of RCWs is used for three specific applications. First, it is an effective management tool to augment and recover small declining populations. Second, it is used to relocate RCWs in a population to provide for optimal spatial arrangements of groups. Third, it is used to transfer genetic diversity between geographically separated RCW populations (USFWS, 2000:85). Translocations are also used to introduce potential mating pairs of RCWs into suitable habitat areas. The practice should be done in proximity to other RCW groups and in conjunction with artificial cavity installment (Carrie and others, 1999:829-831). Translocations can have adverse effects if not used properly. Releasing RCWs in saturated areas can disrupt local populations. Similarly, releasing RCWs into unsuitable habitat areas lacking cavities will cause them to disperse from the area (USFWS, 2000:85-86). Translocations incorporated with artificial cavity creation have been very successful in the stabilization of imperiled RCW populations (Rudolph and others, 1992:914-915; Reinman, 1995:106; Franzreb, 1997:458; Carrie et al., 1999:824).

Small Isolated RCW Populations

The fragmentation of the southern pine forests has created many situations where populations of RCWs have become isolated into small habitat islands. The RCW population on the PWR is a perfect example of one of these situations. Small isolated populations are susceptible to extirpation, local extinction, due to inadequate habitat and

loss of genetic diversity (USFWS, 2000:8). Populations under 50 individuals are thought to be in danger. However, some models have shown that dense populations as small as twenty-five individuals in ten groups can be remarkably persistent. These model results have been seen in actual RCW populations. Reasons for the RCWs persistence in small populations is due to their cooperative breeding system, which creates a breeding buffer. Breeders may die, but are then replaced by helpers. Thus the number of breeders in a small population is able to remain relatively constant (Crowder and others, 1998:1).

The Savannah River Plant Site (SRPS) in South Carolina is a benchmark to recovery efforts of small RCW populations. In 1985, there were only four individual RCWs on the SRPS. In 1996, after extensive management including, translocation of 54 RCWs, insertion of 305 artificial cavities, SFS capture and removal, and forest improvement practices, the population of RCWs rose to 99 individuals (Franzreb, 1997:458-462). The SRPS example proves that small RCW populations can be saved. However, it also illustrates that extensive resources must be used to prevent extirpation. Small populations are important to the recovery of the RCW metapopulation through supporting large core populations with genetic diversity via translocations (USFWS, 2000:127-128). It is important to note that translocations and artificial cavities should be viewed as short-term techniques presently employed so that the RCW will not have to rely on them in the future (Krusac et al., 1995:62).

Private Land Management

RCW populations on private lands, which are mostly small isolated populations, play an important part to the species recovery. Private land RCW populations, just like small isolated populations, are reservoirs of genetic resources for translocation birds and

potential dispersal corridor linkages between large populations (USFWS, 2000:106). Recent trends of decline and extirpation of privately owned RCW populations have been on the rise. The number of active clusters on private lands has dropped under 1,000 (Costa, 1995b:68). Unlike federal lands, private landowners do not have to participate in active conservation and are only required to not remove RCWs or their cavity trees. Therefore, private landowners' role in species recovery, although important, is only voluntary (USFWS, 2000:106-107).

The USFWS has taken proactive steps to provide incentives to private landowners by encouraging them to participate in RCW conservation. Memoranda of Agreements (MOA) are legal agreements between the USFWS and private landowners that outline the actions that the landowner will take for providing RCW conservation. In return, the landowner is shown to be environmentally friendly and will not have to worry about litigation if they follow their responsibilities (Costa, 1995b:72). Individual and Statewide Habitat Conservation Plans (HCP) allow for incidental take and relocation of RCWs. This initiative allows RCWs that are deemed by the USFWS to be imminently endangered in their current location to be properly relocated at the expense of the owner. HCPs save owners the expense of preserving RCW habitat for populations that are at high risk of extirpation (Costa, 1995b:71; Kennedy and others, 1996:23).

The Safe Harbor Program is an agreement between the government and private landowners that own land with RCWs. Under the program, landowners create new RCW habitat on portions of their land without RCWs. In return, they can manage that land however they choose without federal oversight as long as they maintain the number of RCW groups and their habitat that existed prior to the agreement. Therefore, there is no

net loss of RCWs and landowners can manage their land as they see fit (Williams, 1996:26-27). A provision of the program allows mitigation of RCWs in which the landowner receives credit for creating new groups of RCWs. These credits, which allow relocations of RCW groups, can be sold or saved similar to pollution credits. The end result of mitigation credit use is the creation of at least one RCW group for every one group moved (Kennedy et al., 1996:24, USFWS, 2000:110-113). Conservationists have pretty much conceded that recovery of the RCW will occur on federal lands large enough support large populations of RCWs (Kennedy et al., 1996:23). The use of private lands to support the larger RCW populations on federal lands plays an important part in the species recovery strategy (Costa, 1995b:74).

RCW Modeling

In order to predict future populations and conditions, models have been developed to simulate potential RCW population levels under certain constraints. Computer models are a relatively inexpensive way to simulate complex systems composed of a large numbers of variables before large allocations of resources are committed. However, the usefulness and effectiveness of a model is determined by the limits of its reliability in which the model has been successfully tested and validated (Gordon, 1985:4-5). Models to date have used various methods such as: staged-based matrix on life history events; individually-based spatially-explicit logic; foraging behavior based on optimal foraging theory; and multiple objective linear programming (MOLP) comparing timber value versus habitat quality. These models are based on and limited by specific methods and assumptions. Along with modeling, there has been a lot of work done using statistical analysis on population and habitat data. The results of models and empirical analysis of

data have helped predict future RCW population levels. There are still pieces missing in the puzzle to give the complete picture on the outlook of the RCW. Due to the RCW's endangered status and its many unique requirements, modeling is the best means available to help predict future outcomes in order to justify the best management decisions regarding the RCW.

Staged-Based Model. The staged-based model developed by Heppell, Walters, and Crowder used the Leslie Matrix, which determined the RCW population size based on specific parameters and events. The model only incorporated male RCWs because male population dynamics reflect the RCW territorial dynamics better than female population dynamics. The authors justified this because RCWs are territorial birds. Thus only using males can predict population levels. Also, males typically are the sex that performs the helper role in a group. The matrix was based on six different male life history stages crossed against the probabilities of surviving, staying, or moving on from each life stage. The life histories were transitions from: fledglings, helpers, floaters (RCWs that move from group to group), solitary, 1-year old breeders, and 2 or greater year old breeders. Through several iterations of the matrix, growth rate, population level, and fecundity were derived for each life stage. All of the derived variables were combined to determine the effect on the RCW population's overall growth rate due to different management proposals. The model determined that removal of cavity invaders and artificial cavity additions to occupied and unoccupied territories increased the growth rate while female translocations decreased the growth rate. The model was time-independent; instead it explored the changes to growth rates due to parameter changes. Also the deterministic model was limited by considering only large populations and not

taking into consideration spatial and habitat conditions (Heppell and others, 1994:479-486).

Spatial Explicit Model. The need for a spatially explicit, individually based RCW population model was met with the model developed by Letcher, Priddy, Walters, and Crowder. This type of model is desirable in that it simulated life histories of individual birds as they moved around, sequentially showing a complete picture of their population dynamics. However, this type of model required extensive specific data on the RCW. The data obtained for this model came from monitoring records of over 200 groups of banded RCWs during a fifteen-year period (1980-1994) in the Sandhills of North Carolina. The data gathered determined for both male and female RCWs specific probabilities of life events such as death, transition to helper or breeder, dispersal range and direction, and cavity excavations.

The model simulated a segmented landscape composed of numerous RCW territories. A territory consisted of the foraging habitat area and a potential cluster of cavity trees. The territories were initially fixed by the location of cavity clusters but were allowed to change in size and occupancy. The size of the territories' radiuses ranged from 325 to 550 yards depending on the density of cavity clusters. As the cluster density increased, the radius of the cavity cluster decreased. The model used a set of equations based on the probabilities derived from the data to determine the movement and mortality of the birds. Different initial conditions for spacing and RCW numbers were arranged and ran by the model. The model ran the iterations for every season (3 months) to determine the population fluctuations over 100 year timeframes.

The model's results offered a lot of applicable information on RCW population dynamics. Variables from the model's equations were tested to determine which are most sensitive in changing the overall population growth rate. Female mortality and dispersal had the greatest negative effect on growth rate. The model results showed that populations with over 250 territories were independent of initial density and reached a stable population level. RCW populations of 49 highly dense territories and 169 highly dispersed territories were needed to reach stable population levels. With less than 50 territories, the RCW population eventually crashed regardless of initial density. The model is an excellent tool that depicts how a density and initial population size affects the livelihood of RCW populations. The model's limitations were that it did not account for genetic structure within the populations, habitat quality was continuous and independent from the model's equations, environmental stochasticity (randomness) was not accounted for, and no emigration or immigration was allowed (Letcher and others, 1998:1-12). The developers of this model refined it to explore outcomes of exceptionally small RCW populations. Their findings are discussed later in Chapter 5.

Foraging Theory Model. The foraging theory model by Coles, Hughell, and Smith determined theoretically the foraging habitat requirements of the RCW. The model assumed even-age tree stands that were allowed to vary in tree spacing and tree size. Optimal foraging theory states that species will expend the least amount of energy in acquiring the greatest amount of food. Under these guidelines, the model's authors developed equations based on the energy expended by RCWs as they forage tree to tree. The equation for quality of foraging habitat included the trees' spacing and size, which correlates to food availability. Also they determined the amount of energy gained from

acquiring food. The equations were combined together under a fixed foraging time to determine the foraging habitat requirements for the RCW. Thus the energy expended by RCWs must be less than the energy gained from foraging in the available habitat for the habitat to be adequate. The model has not been validated on existing data. However, it demonstrated using the optimal foraging theory as a way to determine sufficient foraging habitat (Coles and others, 2000:1-6).

Economic Model. Roise, Chung, Lancia, and Lennartz developed an economic model that takes into account the trade-offs between providing optimal RCW habitat versus the net present value (NPV) from timber harvests. MOLP was used to determine the various feasible combinations of foraging habitat and NPV. The model defined the requirements of optimal foraging habitat and developed equations with specific measurable variables. Data for the model came from the Savannah River Plant Site in South Carolina, which contains a population of RCWs in 130,000 acres of southern pine forest. Once the different optimal levels of habitat and NPV of timber harvest were determined, the various combinations of optimal levels were simulated. The model's two hundred-year planning horizon had timber stands being harvested under silviculture methods on a hundred-year rotation schedule if colonized by RCWs and on a thirty-year rotation schedule if not containing RCWs. The results showed that there was an inverse relationship between the fluctuating levels of timber NPV and RCW habitat. Smaller amounts of timber harvest equivocate to larger RCW habitat areas and vise versa. With this model's results, forestry managers can find the optimal timber harvest level that will meet desired RCW habitat acreage. The model was limited in that it did not incorporate

the actual RCW populations themselves or take into account various RCW spatial configurations or habitat quality (Roise and others, 1990:6-11).

Population Viability Model. Viability models estimate the minimum population size of a species needed to prevent extinction or local extirpation due to stochastic events. The decline of a species is brought on by: demographic stochastic events such as variations in fecundity; environmental stochastic events such as seasonal changes and natural catastrophes; and genetic stochastic events such as inbreeding or genetic drift (Shaffer, 1981:131-133). Stevens developed two population viability models for the RCW. The first incorporated the Johnson-Emigh-Pollak (JEP) model type that used analytical methods of population size. The second model used Vortex model simulations that took into account the different stochastic variables that affect the RCW. Data used in the models was from the RCW population, consisting of 34 active groups, located at the Piedmont National Wildlife Refuge and Hitchiti Experimental Forest in central Georgia. The JEP model determined that 556 adults are needed for population sustainment. The Vortex model showed that especially large populations over 1,200 adults are needed for sustainment. The main reason for the large size was the loss of heterozygosity (genetic variation). Both models however did not take into account the aggressive management practices being used by RCW managers. Also, the models did not incorporate spatial layouts or the unique cooperative-breeding system of the RCW (Stevens, 1995:227-238).

System Dynamics Model. An area that has not been addressed in RCW modeling is the relationship between the RCW populations and its habitat along with how the RCW population is affected by changes in habitat. There have been studies that reflect the relationship between the RCW population and its habitat. Typically, they show that

RCWs are best suited in areas with large, high density RCW populations that live in understory controlled, old-growth longleaf pine forests consisting of sufficient numbers of foraging pines and cavity trees (Seagle and others, 1987:50-51; Thomlinson, 1995:610-612; Engstrom and Sanders, 1997:214; Hardesty and others, 1997:ii). Studies have also shown that clear-cut sections near RCW clusters are adverse to the RCW population (Beaty, 1986:1; Rudolph and Conner, 1994:371-373; Ferral, 1998:40). The desired outcome of clear-cutting and replanting longleaf pine is to help the RCW in the long term. There is a need to determine the relationship between RCW population levels to changes in RCW habitat. A system dynamics approach is an excellent method to meet this need.

A system dynamics model is able to represent the various relationships between the RCW population and its habitat. The habitat components such as longleaf pines, slash pines, and understory hardwoods along with the RCWs are represented as stocks. The stock levels vary according to different inflow and outflow rates that are determined by the significant relationships. The relationships are determined by using measurable variables. Once the proper structure is determined and validated, changes in habitat levels are made by simulating different timber harvests. The system dynamics model can show the temporal effects on the RCW from different harvest frequencies and amounts. The model can also be segregated into specific areas to simulate spatial effects. Thus the effects of harvests in specific sectors are shown on the aggregate RCW population. The advantage of using a system dynamics model is the ability to simulate general behavior patterns as model variables are simultaneously changing via feedback loops (Forrester, 1991:15).

Shaw Air Force Base

Shaw Air Force Base's RCW population is the focus of the thesis's system dynamics model. Shaw Air Force Base is comprised of two properties located in the east-central section of Sumter County South Carolina. The main base consists of 3,400 acres adjacent to the west side of the city of Sumter. The base's primary mission is the 20th Fighter Wing made up of four F-16 squadrons containing over 100 fighters (Shaw, 1996c:1,5). Shaw also operates the Poinsett Weapons Range located ten miles south of the base. The roughly three by seven mile rectangular range consists of 12,500 acres. A majority of the acreage is heavily forested except the air-to-ground target range and the wetland areas located in eastern and southeastern sections of the range. A regional map showing Shaw AFB and the PWR is shown in Figure 26. The range has been in

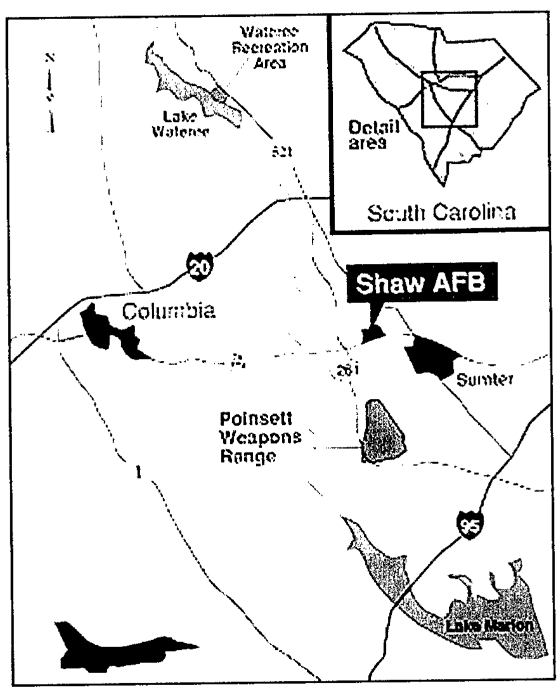

Figure 26: Shaw AFB and Poinsett Weapons Range Location (Shaw, 1994:5)

operation since 1951 and was expanded in the mid-1990s by acquiring 4,935 acres of state and private lands (Shaw, 1996a:1). A majority of the land acquisition came from the Manchester State Forest, which comprises the entire western boarder of the PWR. The rest of the PWR's perimeter is boarder by residential areas. The forested area of the range, which contains various flora and fauna, acts as a target area buffer zone. Shaw AFB actively manages the biodiversity on the PWR to ensure its long-term sustainable use. Also, Shaw AFB incorporates a sustainable yield timber-harvesting program on the PWR using appropriate silviculture practices to obtain desired tree age densities. The timber sales help to offset the range's wildlife management expenses (Shaw, 1996b:61-62; Shaw, 1996c:1). The total estimated value of all of the PWR's timber is approximately $4-5M. The current estimated annual income from the sale of the PWR products, pine straw, pulpwood, and saw timber, is approximately $100K (Shaw, 1996b:13).

The weapons range forested area is chiefly composed of various-aged stands of longleaf pine (2,600 acres in 1996) and slash pine (2,500 acres in 1996) (Shaw, 1996b:3) Longleaf pine is native to sandhill region of the PWR while the slash pine and loblolly pine was planted by former range managers from 1951 to 1985 (Shaw, 1996b:3; Shaw, 1996c:60-61). Turkey oaks are also inter-dispersed throughout the understory of the range. The average elevation of PWR varies around 200 feet above mean sea level. The soils of PWR primarily consist of hydric sandy loam types that are well drained except in the wetland region. Various wildlife exists on the PWR including the endangered RCW. The RCW population on Shaw AFB has been steadily declining in recent years (Shaw, 1996c:10, 52). Currently, there are approximately twenty-five RCWs located in five

active cluster groups throughout the range. All active clusters are located in mature longleaf pine stands (Ryan, D., pers. comm.). The RCW population is considerably small and fairly isolated. The only other adjacent RCW habitat is located southwest of the range in Manchester State forest. The state forest is operated under a timber-harvesting management regime and offers limited favorable RCW habitat except near the southwest corner of the PWR (Manchester, 2000, n. pag.). At this location on the state forest, there exist clusters of cavity trees. The southern most RCW group occupies cavities in both the state and the PWR forest land (Ryan, D., pers. comm.). A map of the PWR is shown in Figure 27.

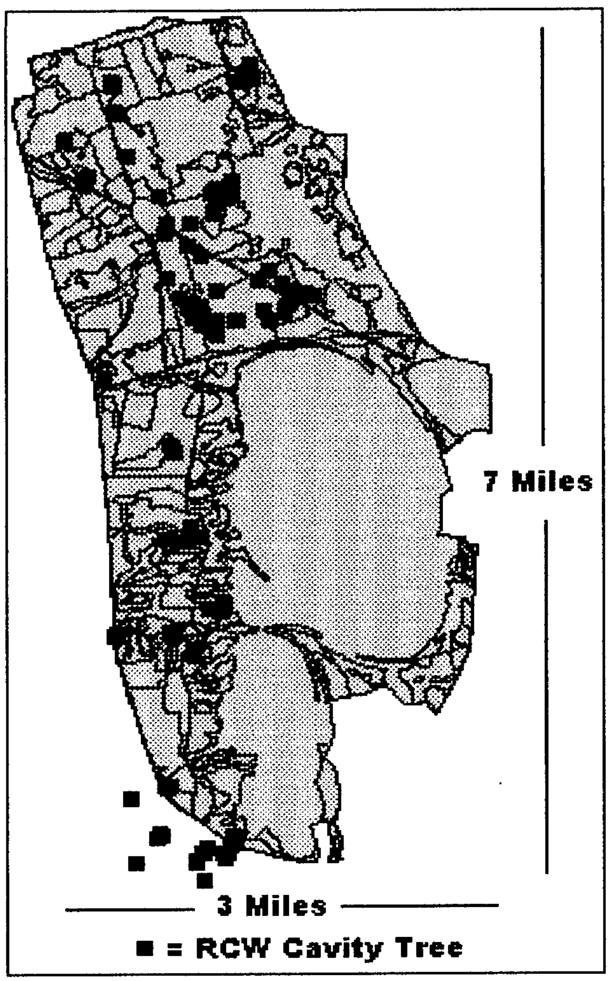

Figure 27: Poinsett Weapons Range

Shaw AFB adheres to the mandated requirements of the ESA, DoD Directive 4700.4, *National Resource Management Program* (DoD, 1989:14-15); AFI 32-7064, *Integrated Natural Resource Management* (DAF, 1997:13); and AF Policy Directive 32-70, *Environmental Management* (DAF, 1994:1-3). The RCW management program used by Shaw AFB is contained in Shaw's Red-Cockaded Woodpecker Plan (Shaw, 1995:1-8) and highlighted again in Shaw's Endangered Species Plan (Shaw, 1996a:36-49). The plans identify the main management concerns for the RCW as breeding success, loss of cavity trees, beetle infestation, understory hardwood control, cavity-invading flying squirrels, and a small population size which leads to genetic drift and possible extirpation (Shaw, 1995:3-8; Shaw, 1996c:52). Measures being employed to counter these problems are: off-limits buffer zone establishment, artificial cavity installment and drilling, five-year prescribed burn rotation, conversion of off-site slash pine to longleaf pine, silviculture tree stand thinning, hardwood herbicide application, removal of flying squirrels, installment of squirrel and snake extruders, retainment of snags to provide habitat for RCW cavity kleptoparasitic species, and translocations of RCWs from distant populations. Shaw also conducted a Geographic Information System (GIS) survey to identify the timber inventory and RCW cavity trees for monitoring records. The GIS mapping database is continually updated to record events such as prescribed burns, clear-cuts, replanting, cavity movement, etc. The RCW population has been identified and banded; nestlings are banded soon after birth (Shaw, 1995:3-8; Shaw, 1996a:36-48). All of the measures that Shaw is taking to manage its RCW population are in accordance with the 2000 RCW recovery plan and all other federal guidelines. Depending on varying home range estimates, the PWR has the future potential foraging and nesting

habitat capacity to provide for thirty to forty RCW groups on 9,500 forested acres (USFWS, 1985:40).

Shaw AFB has recently incorporated a conversion plan to remove slash pine and replant with longleaf pine (Shaw, 1996b:4; Shaw, 1996c:69). The off-site slash pine was introduced into the area because of popular reforestation trends in the mid-1900s that saw the slash pine as a fast-growing pine. Similar to other sandhill regions in the Carolinas, slash pine growth becomes stunted soon after the sapling pole stage (Shaw, 1996c:60-61; Manchester, 2000:n. pag.). This is evident on the PWR with slash pine trees older than thirty year displaying little to no growth (Ryan, D., pers. comm.). Thus as a timber commodity, the slash pine was a poor choice on the PWR. The slash pine on the PWR serves little use for the RCW populations. The RCWs will not excavate cavities in the mature slash pines due to their small diameter size. Likewise, slash pines offer minimal foraging habitat for the RCWs.

The reintroduction of longleaf pine to the existing slash pine areas will provide the optimal long-term habitat for the RCW population in the available forested areas of the PWR. The short-term effects on the RCW are of concern to Shaw natural resource managers. Even though the slash pine provides little for RCW habitat quality, the removal of the slash pine can negatively affect the RCWs. Clusters of longleaf cavity trees will not provide quality habitat if they are surrounded by clear-cut land replanted with longleaf saplings. The slash pine does help in providing buffers for the cavity clusters. Also, slash pine probably provides residual amounts of foraging habitat. Shaw has been clear-cutting five to ten acre sections for a total of about twenty acres of stunted slash pine stands each year (Ryan, D., per. comm.). Shaw's current policy states that

clear-cuts should be no larger than forty acres and be irregular in shape to maximize the forest edge for wildlife (DANAF, 1981:4-7; Shaw, 1996b,7). Income earned from timber harvests can only be used to pay for the PWR wildlife management costs (DoD, 1989:14). The clear-cut areas are not immediately replanted. The areas are burned and mechanically prepared to plant the longleaf seedlings a couple years after the clear-cut. At this pace, it will take a considerable amount of time to convert the slash pine stands to longleaf pine stands. Shaw wants to find the optimal annual rate of conversion that will not adversely affect the RCW in the short-term. In the long run, the conversion will be the best solution for the RCWs on the PWR.

Other Locations Using Conversion

Conversion from off-site pines to native longleaf pines is being studied heavily. The 2000 RCW recovery plan recommends conversion as a means of habitat restoration. To minimize habitat fragmentation, the plan advises that locations employing conversion use irregular shaped clear-cuts no larger than 25 acres, followed then by appropriate site preparations, and finally use direct seeding for regeneration (USFWS, 2000:100). There are a number of locations using conversion for forest restoration purposes. Sand Hills State Forest (SHSF), SC has been undergoing conversion since 1982. Since then, small reproductive rate decreases in the 48 groups of RCWs have been detected on SHSF (Ferral, 1998:40). Ft. Jackson, SC has converted over 8,000 acres to longleaf pine since 1993. Along with other management techniques, Ft. Jackson has approximately raised their RCW population from 37 to 72 individuals (Ft. Jackson, 1999:n. pag.). The Francis Marion National Forest (FMNF), SC, home of one of the largest RCW populations, has plans to convert loblolly pine plantations to longleaf pine. FMNF's strategy is to increase

its 37,000 acres of longleaf pine to 44,700 acres in the next ten years and then to 53,000 acres in the long run (FMNF, 2001:n. pag.). Short-term results on the impacts of conversion on the RCW are inconclusive. The long-term effect on the RCW due to conversion will not be know for decades. In the meantime, modeling is the best course of action in deciding optimal longleaf pine conversion rates and amounts.

3. Methodology

Modeling Approach

Managers of ecosystems face a great challenge in performing their jobs. There are multiple goals, requirements, and constraints that environmental mangers have to address when creating a management plan. The difficulty is in trying to put the management requirements into equal terms and then determining how the requirements interact. The functions of most environmental system are not understood, thus leaving the creation of management plans without a fundamental scientific basis (Woodley, 1993:166-171; Slocombe, 1998:490-491). Such a dilemma is presented with the management of the RCW in the southern pine forests. The habitat requirements for the RCW have been well established, but how the requirements interrelate to affect the RCW is not fully understood. The questions explored in this thesis pertain to the relationship of slash pine to the foraging habitat of the RCW and to the habit fragmentation effect on the RCW resulting from conversion of slash pine to longleaf pine.

To address the complex problems of environmental modeling needed for a fundamentally based management plan, the system dynamics process can be used. The system dynamics process explores the relationships and interactions between numerous changing variables through time. Complexity brought about by multiple dynamic variables makes model logic hard to conceptualize. Mental maps (causal connections of influences) of these complex models get confusing when trying to incorporate feedback loops, variable interdependence, time delays, and non-linear relationships (Forrester,

1994:13). The classical system dynamics method follows iterative steps that focus on the underlying mechanisms that drive system behavior.

System Dynamics Process

The system dynamics process allows exploration of the effects on ecosystems of different management techniques applied at different magnitudes and time scales. This allows installation natural resource managers to simulate the outcome of proposed scenarios, offering insight on managing timber and endangered species without sacrificing mission capability. The focus of the model is the PWR ecosystem, but the structure of the model represents the southern pine/RCW ecosystems overall. The system dynamics methodology goes through the following stages: conceptualization of the problem, formulation of the model, testing of the model, and implementation of the model. The process requires iterations between the stages to build the most accurate and valid model possible. The methodology for the system dynamics process is employed for the methodology of this thesis.

Conceptualization

The conceptualization stage is for researching the topic and gaining as much insight as possible of the problem at hand. Shaw AFB personnel outlined what they would like to gain from a model of their weapons range. This insight from Shaw was used to guide the direction of the research. Research questions and objectives were formulated to aid in the direction of the thesis research. Once a basic understanding was reached on the direction, a literature review was conducted on the topic.

<u>Literature Review</u>. For this thesis, it was necessary to comprehend the key elements and relationships that drive the southern pine ecosystem. Information was

gained through published journal articles, past theses, field reports, and communication with RCW experts and managers. Shaw AFB provided timber and RCW data along with current information on the current management techniques. The knowledge gained during the literature review helped develop the mechanistic structure of the model. The literature review continued throughout the thesis process to address questions that came up during model development.

Problem Statement. To help guide the thesis process, a problem statement was composed. The question to be investigated was, what are effects on the survival of the RCW to habitat fragmentation resulting from conversion of forests from slash pine to longleaf pine. Only logic and components that support insight on the problem statement were included in model. The problem statement was developed by the thesis customers, which included, Shaw AFB, thesis committee, and model builder.

Reference Mode. The culmination of the literature review, direction from the problem statement, and analysis of historical data from the ecosystem allowed for an initial dynamic hypothesis to be formulated. The reference mode hypothesized the expected system behavior under current conditions. The relevant variables that composed the ecosystem's reference mode were: the RCW, foraging-age longleaf and slash pine trees, and the nesting-age longleaf pine trees. The reference mode outlined the initial interpretations of how these key variables interact.

Influence Diagram. The accepted reference mode was a guide to creating the influence diagram. The diagram outlined the cause-and-effect relationships between the entities relevant to system structure. Based upon information from the literature review, the relationships, feedback loops, and driving mechanisms were shown. The extent and

level of aggregation of the entities involved was limited by the system boundary. The boundary was set by the problem statement and level of detail that was warranted by the customers. Components of the flow diagram were amended throughout the model development to create the most accurate causal diagram.

Formulation

The system's mechanisms determined in the influence diagram were used to create the flow diagram. The flow diagram consists of stocks connected by flows driven by flow equations. The flow diagram was developed directly from the relationships displayed in the influence diagram. No additional logic was added to the flow diagram that was not in the influence diagram. The system dynamics model was constructed by coding the flow diagram into the STELLA computer modeling software. STELLA, created by High Performance Systems, performs numeric integration on multiple simultaneous differential equations. STELLA utilizes different numerical integration methods to compute model entity values during simulation. For the thesis, the model employed the Euler method to perform numeric integration. The icons used by STELLA are shown in Figure 28. The model developed for the thesis contained five main

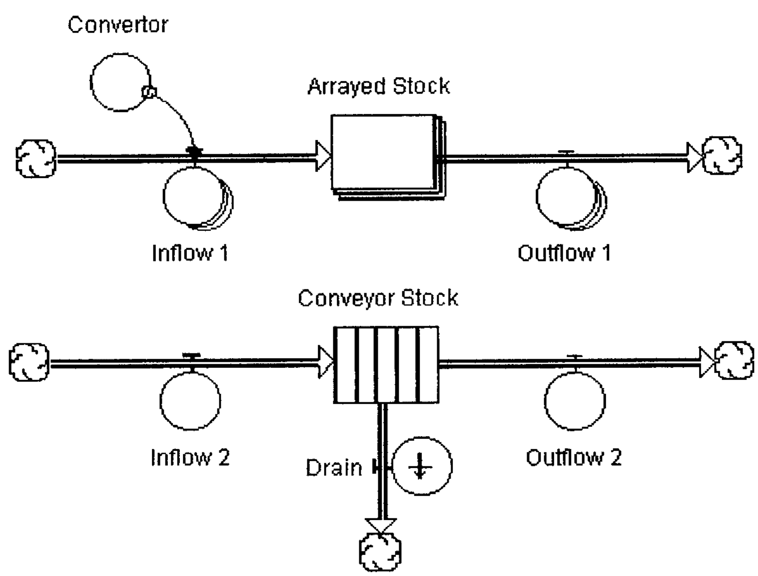

Figure 28: STELLA Icons

sectors: RCW, longleaf pine, slash pine, foraging index, and cavities. Also, six other smaller sectors contained supporting variables used by the main sectors. All model sectors are shown in Appendix B. Assumptions regarding variables, parameter values, equations, or relationships in the model were consistent with the problem statement and customers' concerns.

Testing

System dynamics modeling concentrates on exploring system behavior trends and relevant magnitudes instead of trying to predict exact numerical output. Thus, statistical tests are not use to validate system dynamics models (Forrester and Senge, 1996:421). System dynamics models cannot be validated by a single test. Instead, confidence gradually increases as the model passes more tests and reflects empirical reality (Forrester and Senge, 1980:209). The thesis model was verified and validated, given its assumptions, to build confidence in model logic, structure, and output. Iterations between the modeling steps were performed multiple times during the testing process to correct for errors in the model structure and/or theorized system behavior.

Verification. The model's structure was built sector-by-sector to ensure that the model represented the relevant mechanisms in the system. The forest and forest management sectors were built first since they controlled the RCW sector. Foraging and tree cavity sectors were devised to relate the forest conditions into factors that affect the RCW. The RCW sector was built last using the inputs from the previously described compartments. Each compartment was individually verified before the next one was built. A number of graphical gauges were used to monitor all of the inflows, outflows, and stocks to ensure proper model behavior.

Validation. Initial model simulations were conducted to test for reference mode behavior. This was necessary to ensure that model variables, structure, and driving mechanisms were working to represent the ecosystems behavior. If problems arose in achieving reference mode behavior, then model adjustments were made. At this time, critical flaws were determined in the model as well in the logic of the dynamic hypothesis. In whatever event, corrections were made to ensure that the reference mode and the model represent the behavior of the ecosystem.

There were a number of validity tests conducted on the model. Behavior anomaly tests traced anomalous behavior back to the source within the model structure, leading to the identification of modeling or theory error. The boundary adequacy tests made sure that the model structure was correct for the model's assumptions. In this test, assumed parameters, structure, and logic were altered to show that model behavior was dependent on the set assumptions. Family behavior tests ensured the model output conformed to accepted behavior of the model's general structure. Extreme condition tests explored the plausible ranges on model inputs and parameter values so that the model output was still within reason.

Sensitivity tests determined what components of the model were affected the most by manipulation within the model. These tests demonstrated where more detail and accuracy was needed in model structure due to swift changes in output from minor model alteration. The customers reviewed the sensitivity test results to determine validity of the output. If counterintuitive results were shown, then the customers needed to examine the behavior to determine if model modification was necessary. Further sensitivity tests were performed until all customers were satisfied that the model was an accurate

representation of the ecosystem. Sensitivity tests helped determine the reasonable boundaries of model entities in which the model output remains valid (Forrester et al., 1980:212-223).

Implementation

Testing Management Decisions and Policies. The general purpose of this model is to provide ecosystem managers of southern pine forests insight into the relationship between the RCW and its nesting and foraging habitat. A detailed model enables prudent forest management practices to be developed that affect the livelihood of the RCW. The model was tested using a variety of different combinations of management practices. The simulations of the model allowed for exploration of various management strategies on the PWR ecosystem. The model design allowed for modification of inputs and structure for use in other southern pine ecosystems supporting small RCW populations.

Presentation of Findings. The results shown from the testing of the model were consolidated and deciphered into a form that can facilitate the use of the model for Shaw AFB decision-making purposes. Discoveries from the model were explained so that the phenomena driving the ecosystem were understood. Limitations and assumptions of the model were emphasized to ensure the full comprehension of the model's scope, structure, and usefulness. The final product delivered to Shaw AFB provides insight on various management strategies so they can effectively manage the PWR's ecosystem with respect to the RCW, long-range stability of range resources, and continued Air Force mission capability.

Model Background

Influence Diagram. Upon completion of the literature review and theorization of initial reference modes, the influence diagram of the RCW and its habitat was outlined. The influence diagram was segregated into large sectors made up of entities that represent different parts of the southern pine ecosystem. The sectors and entities were connected together by how they influence each other. Also included in the influence diagram was the determination of the model's system boundary. Model control inputs were located outside the system boundary. The influence diagram was altered and amended throughout the model development process. A general depiction of the model's influence diagram is shown in Figure 29. The main sectors of the ecosystem are shown along with how they influence each other. A plus sign (+) represented a positive influence and a minus sign (-) represented a negative influence on a component from the influencing component. Loops created between entities by influences were categorized as either compensating (C) or reinforcing (R). Compensating loops alone brought behavior patterns between variables to steady-state conditions whereas reinforcing loops alone supported expansive behavior patterns between variables. Double slashes across influences denoted the system boundary. Variables outside the system boundary were independent and not influenced by other model variables. Therefore, the independent variables are model inputs, which were set by the modeler. The final detailed influence diagram of the southern pine ecosystem is located in Appendix B.

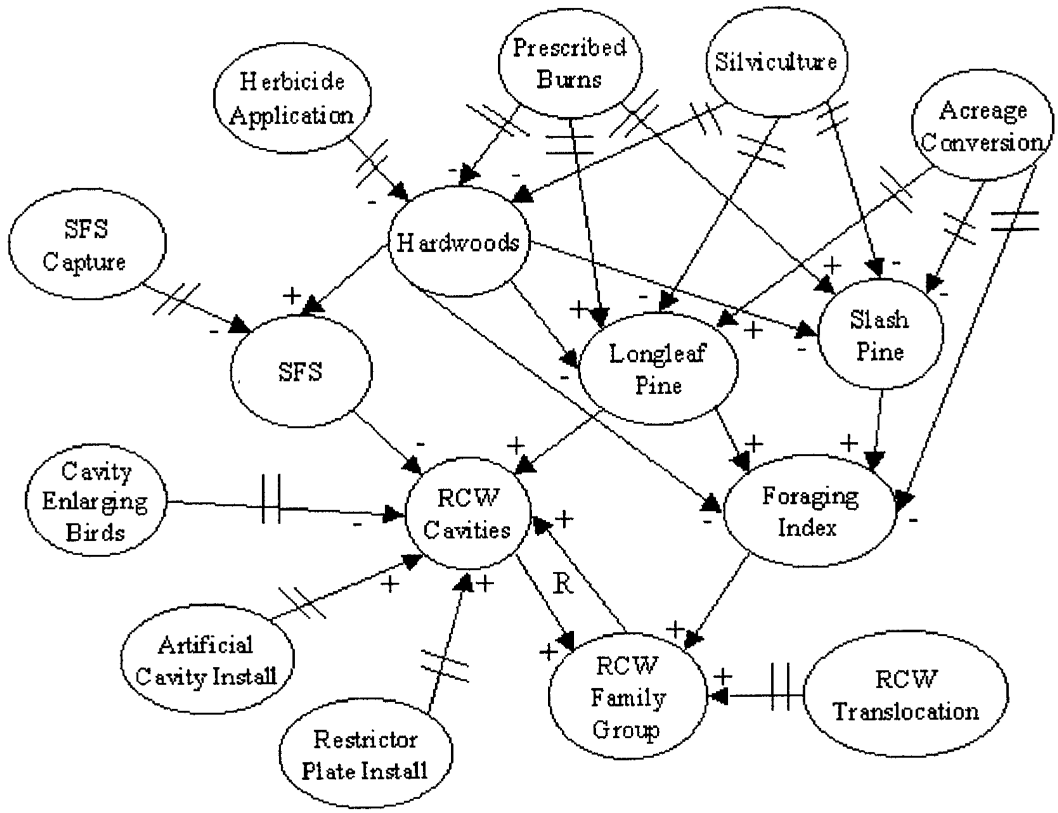

Figure 29: General Influence Diagram

Model Development. The thesis's system dynamics model was based both in spatial and temporal scales. System Dynamics theory explores behavior of systems over a given time interval. The STELLA software program displays the behavior of flow diagrams in incremental time steps. During each step, the equations of the flow diagram are evaluated and requested entity values are displayed. The value of each entity after a time step is used in the calculation of equations for the proceeding time step. In the thesis model, the time step used was one year. All of the model equations and structure was based on annual rates and occurrences.

A spatial model was ideal to address the unique characteristics of the RCW. The traits of the RCW that apply spatially include: living in family groups of birds under a cooperative breeding system; group territorial defense from trespassing RCWs; immigration of birds between groups; required clusters of adjacent old pine trees for nesting cavities; and adequate foraging quality in a limited area. To incorporate a spatial scale, the modeler divided the forested land of the PWR into twenty potential areas that can support a RCW group. The division of the areas took into consideration the following factors: past and present cavity tree cluster locations; active RCW family group locations; tree stand layout; geographic boundaries; weapons range operation areas; and reasonable potential home range size. The area sizes ranged from 195 to 430 acres. Under this layout, the assumption was made that the weapons range can support twenty RCW groups, one for each area. Although two groups could possibly coexist in one of the geometrically created areas, it was assumed that only one RCW family group could occupy an area. The area configuration of the PWR is shown in Appendix A.

Model Data. The input data used in the model was a combination of information from Shaw AFB, scientific data from RCW research, and intuitive values where data did not exist. Data from Shaw AFB was obtained from their GIS database and RCW field records. GIS is a map-based database containing information on overlapping levels of particular items of interest. The Shaw AFB GIS information used in the model was the following: the number of longleaf pine, slash pine, and hardwood trees in each stand; tree stand age classification; recent management application locations of prescribed burns, thinnings, herbicide use, and conversions (clear-cut and then replant); and the location of RCW cavity trees (past and present). Current field data records containing the

breakdown of existing location and numbers of the RCWs was used in the model. Also included in the model was approximately 300 acres of the Manchester State Forest near the southwestern tip of the PWR. The section included from the state forest contains cavity trees that are used by a group of RCWs located at the southern tip of the PWR. RCWs in this group use trees from both forests. The remainder of the PWR was cut off from other areas of suitable RCW habitat by the wetlands and residential areas. Thus, RCWs on the PWR are an isolated population limited to the weapons range for their habitat. The data from Shaw AFB and descriptions on how the data was compiled for model input is located in Appendix A.

Model Structure

The influence diagram representing the southern pine ecosystem was used to guide construction of the flow diagram. The final STELLA system dynamics flow diagram of the PWR's ecosystem contained eleven sectors. The inter-connected sectors contain the natural and human components that make up the mechanisms of the model. To account for the spatial requirements of the model, the STELLA array design feature was used to represent the twenty areas on the PWR. Arrays limit flow diagram congestion by allowing repetitive stocks from each area, such as trees classes, to be represented in a single stock icon. Sectors' stocks, flows, and connectors, were constructed according to the logic obtained from the literature review and from the numerous general and detailed assumptions on component interrelationships. The logic was transcribed into the model's flow and converter equations. The flow diagram structure is located in Appendix B. Significant equations are listed later on in Chapter 3

with the structure descriptions. The equations and values from the flow diagram are located in Appendix C.

Forest Sectors

The model contained three tree sectors, two pine tree and one hardwood, which comprised the forest ecosystem. The two pine sectors, longleaf and slash pine, were fairly similar in model design logic. They were both segregated into arrayed age class stocks. The array structure allowed the model to represent the different forest types and age ranges according to the twenty areas on the PWR. The age classes allowed an accurate depiction of the influences on trees at different ages. Also, these age class stocks were set up in a conveyor mode. Conveyors in STELLA move materials through the age class stock and then into the proceeding age class stock at the rate of the model's defined time step. Conveyors enabled the model to represent a smooth transition of trees through the various age stocks as in reality. The age class system displayed the growth of trees along with which class was dominant for the particular state of the forest. The forest in an area, if undisturbed, would eventually reach a steady-state condition between the various tree age classes with the oldest-age class dominating. Initially, the forest was in various transitional stages according to the model input data for each area.

All of the tree age classes were subjected to a mortality rate due to fire and intraspecific tree density saturation. The loss from fire was proportional to the fire intensity. Older age classes were more resistant to fire than younger classes. The mortality rate increased for an age class as it neared the set acreage's carrying capacity. The carrying capacity for older age classes was lower than previous classes. This occurred because of increased nutrient requirements for larger trees. As the forest grew,

different age classes dominated and reached their carry capacity. After trees matured into the next age class, the amount of trees in the former age class declined below their carrying capacity. This was because trees in pine forests typically grow together in stages. Assumed in the mortality rates was natural mortality and environmental stochastic events such as lightning strikes and insect infestation. Older age classes were also subject to management silviculture thinning.

The reproduction of pine trees was dependent upon the number of seed trees, shading effect from older trees, seed germination assistance from the effects of fire, and encroachment of hardwoods. The older tree classes made up the seed trees that supply annual amounts of pinecones. The "Shading Effect" accounted for the restricted amount of light that reached small trees due to large trees. Southern pine dependence on fire was represented by the "Fire Effect" variables. Fire promoted the opening of pinecones for seed release. Also, fire prepared a clear nutrient bed of soil for the released pine seeds. The presence of hardwoods deterred pine growth due to nutrient uptake and shading. The hardwood presence phenomenon was addressed in the model by the "Hardwood-Choking Factor." The longleaf pine sector contained an additional branch of age classes representing slash to longleaf conversion planting. The separation of the planted longleaf seedlings represented in the model the effect that clear-cut areas have on the RCW foraging habitat. The planted longleaf was considered part of the longleaf forest once the planted longleaf developed into potential foraging habitat at the age of thirty years. During conversion, slash pine age stocks were harvested and slash pine acreage decreased according to the acreage conversion rate. Harvesting in turn initiated planting

of longleaf pine seedlings on the converted land. A delay of three years occurred between clearing and replanting to account for the necessary site preparation.

Descriptions of the pine age classes along with any other relevant supporting information are outlined after the basic equations for the pine tree age classes. "[Area]" represents an arrayed variable. "Pro" = Proportion from 0.0 to 1.0.

$$TGen[Area] = TSeed*ST[Area]*TC[Area]*FE[Area]*SE[Area] \quad (1)$$

TGen = *Tree Regeneration* (Trees): New Tree Growth

TSeed = *Tree Seeding Amount* (Seedlings/Tree): Per Seedtree

ST = *Seed Trees* (Trees): Oldest Pine Age Classes

TC = *Tree Hardwood Choke Rate* (Pro): Effect of Hardwoods

FE = *Fire Effect* (Pro): Germination After Fire

SE = *Shade Effect* (Pro): Older Trees Absorbing More Light

$$TS[Area](t)=TS[Area](t-dt)+(TG[Area]-TM[Area]-TL[Area])*dt \quad (2)$$

TS = *Tree Age Class Stock* (Trees): Conveyor Stocks

TG = *Tree Age Class New Growth* (Trees): Trees from Preceding Age Stock

TM = *Tree Age Class Maturation* (Trees): Trees Leaving to Proceeding Age Stock

TL = *Tree Age Class Loss* (Trees): Trees Death

$$TL[Area]=TS[Area]*(TMR[Area]+TFL[Area]*FMM+TPC[Area]*Silvi[Area]) \quad (3)$$

TMR = *Tree Age Class Mortality Rate* (Pro): Based on Density Dependent Graphical Curve

TFL = Tree Age Class Fire Lose (Pro): Based on Fire Intensity Dependent Graphical Curve

FMM = Tree Fire Mortality Magnitude (unitless): For Calibration Purposes

TPC = Tree Age Class Silviculture Percent Cut (%): Mgt Tool

Silvi = Tree Silviculture (unitless): Yes or No

Longleaf Pine Seedlings. The seed producing longleaf pine trees produced pinecones that contain the longleaf pine seeds. The growth of this age class began upon seed germination. The highest germination rate of seeds occurred after prescribed burns. This initial longleaf age class has a conveyor time of five years. Not all seeds germinate upon release. Some seeds lay dormant waiting for ideal germination conditions. The conveyor time frame approximated the average time necessary for seeds to germinate upon release. Once the seedlings leave this age class, they were considered one-year-olds. During this time, the seedlings were especially vulnerable to fire. The seedling saturation density was assumed to be 500 seedlings/acre..

Longleaf Pine Seedlings Planted. Seedlings raised in nurseries were used for replanting in clear-cut areas. The planted longleaf seedling stock has a time duration of only one year, thus leaving the age class at one year in age. This took place because the seedling was already developed and did not need to undergo germination. The planted seedlings do not have intraspecific competition pressures since they were appropriately spaced when planted. Ideal planting densities were 500 seedlings/acre. The seedlings displayed maximum growth due to maximum exposure to sunlight. Planted seedling

fields were protected from prescribed burns by appropriate management techniques represented by "Fire Protection" in the model.

Longleaf Pine Saplings (1 to 15 Years). During the sapling stage, the main stem displayed exceptional height growth to rise above potential ground fire zones. This represented the adaptation of southern pines to frequent fires. Thus mortality from fire decreased greatly compared to the seedling age class. Sapling saturation density was assumed to be 300 saplings/acre. The dbh of longleaf saplings ranged from 0 to 4 inches.

Longleaf Pine Planted Saplings (1 to 15 Years). As with non-planted saplings, planted saplings displayed exceptional main stem height growth. Natural mortality rates were also the same for the two age classes. Mortality from fire was decreased in the planted sapling stock, compared to the non-planted stock, to account for additional preventative care given to prescribed fires in re-planted areas. There was no carrying capacity loss in the planted sapling stock because it was assumed that planting spacing minimized competition among saplings. Dbh was assumed the same for non-planted saplings as for planted saplings.

Longleaf Pine Small Pole (15 to 30 Years). This age class accounted for pine trees larger than saplings, yet not suitable for RCW foraging. The small pole age class was affected by fire and density mortality rates similar to the sapling age class. The mortality from fire and the carrying capacity were both smaller than the sapling age class. Small pole age class saturation density was assumed to be 150 trees/acre. Introduced in the model was the ability to thin the age class for silviculture purposes. The dbh for this age class ranged from 4 to 8 inches.

Longleaf Pine Planted Small Pole (15 to 30 Years). Similar to the non-planted small pole age class, the natural mortality rates were the same. As with the planted saplings, the small pole age class has no carrying capacity loss. At the end of the planted small pole age class, it was assumed that the pine trees were suitable for RCW foraging. Therefore, the model no longer segregated the planted pine tree stocks from the non-planted pine tree stocks. Dbh was assumed the same for the non-planted small pole class as for the planted small pole class.

Longleaf Pine Large Pole (30 to 60 Years). The trees in this age class were capable of providing foraging habitat for the RCW. Also, this was the age class in the model that combined planted longleaf pine areas with the rest of the forest. As before, fire mortality and carrying capacity decreased from the preceding age class. Large pole saturation density was assumed to be 100 trees/acre. Silviculture thinning was possible in this age class. The dbh for this age class ranged from 4 to 16 inches.

Longleaf Pine Mature (60 to 90 Years). The trees in this age class provided ideal foraging habitat for the RCW, better than the preceding age class. Again, the fire mortality and carrying capacity decreased from the preceding age class. Mature pole saturation density was assumed to be 50 trees/acre. Silviculture thinning was possible in this age class. Trees in this age class were capable of supporting installment of artificial cavities for RCWs though RCWs themselves were not likely to construct cavities in these trees. The dbh for this age class ranged from 16 to 20 inches.

Longleaf Pine Old-Growth (90+ Years). Old-growth trees provided excellent foraging habitat. The concepts of fire mortality and carrying capacity were the same as with the other age classes. Old-growth saturation density was assumed at 30 trees/acre.

Until change such as a wildfire or timber harvesting, the old-growth age class was the dominant age class in the forest. Silviculture thinning was possible in this age class. RCW were able to construct cavities in old-growth trees. Also, artificial cavities could be installed in old-growth trees. The dbh for this age class was over 20 inches with an average of 22 inches.

Slash Pine Age Classes. The slash pine age class breakdown was the same as the longleaf except slash pines do not have an old-growth age class. The model represented slash pine growth and mortality behavior similar to longleaf growth. The slash pine age classes were of the same duration except for the mature slash pine stock that represented trees age 60 and older. Mortality rates for the slash pine age classes were higher than the longleaf age classes. The higher mortality rates were due to the slash pine's poor growth on the PWR. The poor growth rates were due to the range's non-optimal soil types. Carrying capacity for the slash pine age classes was similar to that of the longleaf age classes. However, dbhs for slash pine stocks were smaller than longleaf age class dbhs due to the poor slash pine growth. Large pole slash pine and mature slash pine age classes were considered RCW foraging habitat. Conversely, the slash pine age classes' foraging quality was less than the longleaf pine age classes. In the model, slash pines were not capable of supporting RCW cavities. Slash pine age classes were also able to undergo silviculture thinning similar the longleaf age classes. During conversion from slash pine to longleaf pine, slash pine trees were harvested completely in all age stocks for the set conversion acreage.

Hardwoods. Hardwood trees of various ages were located throughout the PWR. The density and age ranges of the hardwoods in different areas depended upon recent

management applications. Shaw employs prescribed burning, herbicide application, and mechanical removal of hardwoods on the PWR. If left unchecked by these management practices, hardwoods would dominate the range's ecosystem by choking out young pine trees.

The hardwood sector was structured into two arrayed age class stocks. Similar to the breakout of the pine trees, the density of hardwoods was spatially considered in the model's arrayed structure. The sapling age class was represented by a fifteen-year conveyor stock. Unlike pine trees, hardwood saplings were not as dependent upon direct sunlight. Thus, hardwoods could regenerate quickly and take over the forest floor. Hardwood growth in the model was controlled by the amount of older seed-bearing hardwoods and density of saplings. Hardwood seedlings, like pines, also encountered intraspecific competition that reduced the amount of seeds that sprouted at higher seed densities. The hardwood seedling age class mortality was from carrying capacity losses and fire losses. Hardwood sapling carrying capacity was assumed to be 600 saplings/acre. Saplings were not fire resistant like pine saplings. Therefore loss from fire was high in this age class.

The second hardwood age class in the model was the pole class. This class represented all of the hardwoods larger than saplings. Management of hardwoods focused on the pole age class because of their production of seeds. Mortality in this age class was due to many factors. The carrying capacity, which increased mortality at higher densities, was assumed to be 100 trees/acre. Fire killed a number of trees in this age class. However, older hardwoods often resprout after being burned. The model also allowed for use of other management tools. Herbicides could be applied to pole

hardwoods, which in turn permanently killed the trees. Also, mechanical removal of the trees could be applied to the age class at variable removal amounts.

To represent how hardwoods affected the growth of pine trees, a "Hardwood-Choking Factor" was created in the model. Pole hardwoods were weighted more in the factor because they produced seeds and shade that affected the pine seedlings and saplings. Hardwood saplings also were included in the hardwood factor because they directly competed with the younger pines. The hardwood factor was used in the longleaf pine and slash pine sectors in determining the hardwood effect on pine growth.

Forest Management Sectors

The model includes four different forest management techniques that could be engaged. Just as with the tree sectors, the management sectors were designed in an arrayed structure. This allowed for the application of management strategies at different rates and magnitudes in various areas on the PWR. This also enabled the study of different combinations of management applications.

Prescribed Burning. The main management tool in the model was prescribed burning. The mortality that occurred in each tree age class due to a fire was dependent upon the age class's own fire mortality rate curve and the fire intensity. For each tree age class, a fire mortality curve was set up to reflect greater mortality rates in the age class at greater fire intensities. The older the tree age class stock, the lower the mortality was from respective fire intensity levels. Fire intensity built up after every fire. The model represented "Fire Intensity" as a stock whose value ranged from 0 to 1. Right after a fire, the Fire Intensity equaled 0. As time progressed after a fire, the intensity built up. The rate of intensity build up was proportional to the amount and size of trees left in the

forest. The model allowed for intensity build up faster with greater numbers of older trees. It was assumed that it took fifteen years for the Fire Intensity to build up to a value of 1. Fire intensity remained at 1 until a fire occurred. Added to the prescribed fire sector was the ability to simulate a wildfire. When the model engages a wildfire, the Fire Intensity automatically was assumed to equal 1.

Fire also played a part in the growth of pine seedlings in the model. A conveyor stock was used to represent what the fire effect was on the pine seeds. The "Fire Effect" stock ranged from 0 to 1. Right after a fire occurred, pine seed germination was relatively high due to a rich nutrient supply from the fire ashes and the death of hardwood saplings that actively competed with pine seedlings. The corresponding Fire Effect after a fire was 1. As time passed after the fire, Fire Effect diminished exponentially as the nutrients were used up and new hardwood saplings begin to sprout. The time for the Fire Effect to drain out in the conveyor was five years. The Fire Effect after five years was 0 until a new fire occurred. Equations for fire intensity and effect are shown next.

$$FI[Area](t)=FI[Area](t-dt)+(FIB[Area]-FIL[Area])*dt \qquad (4)$$

FI = *Fire Intensity* (Pro): Intensity Level

FIB = *Fire Intensity Build* (Pro): Based on Number of Trees

FIL = *Fie Intensity Loss* (Pro): Occurs Only After a Fire

$$FE[Area](t)=FE[Area](t-dt)+(FIP[Area]-FT[Area]-FD[Area])*dt \qquad (5)$$

FE = *Fire Effect* (Pro): Pine Germination Effect Conveyor Stock

FIP = *Fire Input* (Pro): Inputs when a Fire Occurs

FT = *Fire Thru* (Pro): Conveyor Transition Time

FD = *Fire Drain* (Pro): Exponential Loss of Fire Effect

Herbicide Application. Another type of management method used to control hardwood growth was the application of herbicides. This was an effective management tool that has longer lasting effect on older hardwoods than prescribed burning. The disadvantage to herbicide use was that it is more labor intensive, time consuming, and costly. Once applied to a hardwood, the tree would die and not resprout, like what happens with burned hardwoods. The herbicide application considered in the model was the injection type, which was only applied to older hardwoods. The model represented the "Herbicide Effect" as a single stock. The herbicide killed off the pole age class hardwoods at the given percent of trees applied. Hardwood saplings were not directly affected by herbicide application.

Silviculture. Forest management often uses silviculture methods to control the density of age classes. Silviculture allows foresters to help a forest reach its carrying capacity faster, while at the same time make a profit from harvested trees. The model enabled various amounts of older age classes, small pole and older, to be thinned from each tree sector.

Acreage Conversion. The management tool of most interest in the thesis was converting acreage from slash pine to longleaf pine. The ultimate long-range goal for managers of RCW southern pine ecosystems is to convert all forest types to longleaf. The difficulty is to find the amount of annual conversion that can be done that would not harm the RCWs in the short-term due to the effects of habitat fragmentation. The model

structure in this sector was set up to allow for conversion at different amounts, rates, and spatial layout.

Three acreage stocks were used to represent the different forest types in the model. The conversion flowed from slash pine acreage stock, to converted longleaf area stock, and then finally to longleaf acreage stock. The initial amount of slash and longleaf acreage was about the same according to the current conditions at the PWR. As mentioned in the longleaf sector, the converted acreage was segregated from the rest of the forest acreage. This allowed the model to represent how habitat fragmentation from conversion affects the RCW. Acreage initially flowed from the slash acreage stock to the transitional converted acreage stock. This flow represented the clear-cutting of slash acreage followed by the replanting to longleaf seedlings. There was a three-year delay between clear-cutting and planting to account for the necessary site preparation. The converted longleaf acreage stock was modeled as a 28-year conveyor. The 28 years corresponded to the time that it took from the initial clear-cut to the time that the planted longleaf became part of the RCW longleaf foraging forest. Conversion continued in each area until all of the slash pine was replaced with longleaf pine.

RCW Habitat Quality Sectors

Three additional sectors were used in the model to show how the RCW was dependent on the conditions in the southern pine ecosystem. The southern flying squirrel (SFS) was modeled because of the interspecific competition for suitable cavities that was placed on the RCW by the SFS. Tree cavities were included in the model due to the RCWs high dependence on the cavities for survival. And finally, a "Foraging Index" of forest variables was devised to reflect the impact of foraging habitat on the RCW. As

with all previous sectors in the model, habitat quality sectors were set up in an arrayed structure to reflect the conditions in each area of the PWR.

Southern Flying Squirrel. SFSs compete with the RCW for non-enlarged cavities because they were small enough to fit into the cavity opening. The SFS was simply modeled by two age class stocks, juvenile and adult. The SFS was directly affected by the amount of hardwoods in the area. Hardwoods provided the majority of the SFS's food supply, thus affecting birth and mortality rates. The model assumed equal amounts of male and female SFSs. The model also assumes that two SFS adults could produce at most three juvenile SFSs each year. The juvenile SFSs became adults after one year. Squirrel boxes are used by forest managers to capture SFSs. This management technique could be engaged in the model for the capture and removal of SFSs.

Cavities. Suitable tree cavities are critical to the livelihood of RCWs. The model assumed that cavity trees were from the old-growth longleaf pine age class. However, the mature longleaf pine age class trees could support artificial cavities. Cavities were the only long-term means of shelter that RCWs would accept. If an area did not contain a sufficient amount of acceptable cavities, then RCWs dispersed from the area. The model broke the cavity sector down into four different stocks that represented cavities occupied by RCWs, cavities occupied by SFSs, degraded unacceptable cavities, and vacant acceptable cavities. Each of the four types of cavities could be lost due to mortality of the cavity tree. The cavity tree mortality rate was higher than the normal mortality rate for pine trees of that age due to the cavity weakening the tree. The cavity flow equations between each stock were rounded due to the relative importance of each individual cavity.

The three types of acceptable RCW cavities, RCW occupied, SFS occupied, and vacant, could all become unacceptable cavities. This occurred due to cavities degrading from old age and/or enlargement from larger woodpeckers. The model allowed input on different numbers of cavity-enlarging birds into the model, which in turn increased the rate of cavity degradation. A management technique used in the model to recover enlarged cavities was to place cavity hole restrictor plates over the cavity opening. The model simulated this management practice by moving cavities, after they have had restrictor plates installed, from the unacceptable stock to the vacant stock. The vacant cavity stock became either a RCW occupied stock or SFS occupied stock. RCWs new to an area would occupy the vacant cavities. SFS would take vacant cavities depending upon the numbers of SFS in the area. When either SFSs or RCWs died or vacated their respective cavity, the cavity was then returned to the vacant cavity stock. New cavities were constructed by the RCWs in an area. Cavity construction rates ranged from two to four years to construct a cavity. When RCWs occupied a high percentage of the acceptable cavities, then the pressure to construct new cavities was high. When new cavities were constructed, they became a new cavity in the vacant cavity stock. Another management tool that could be used in the model was to insert artificial cavities into either old-growth or mature age class longleaf pines. When artificial cavities were incorporated into the model, they were added to the vacant cavity stock. The two management tools for providing acceptable cavities to an area, restrictor plates and artificial cavities, play a crucial part in re-colonizing RCWs into areas capable of supporting RCWs. The equations that govern RCW and SFS occupancy of cavities are shown next.

$$CavSFS[Area](t)=CavSFS[Area](t-dt)+(CavSFSTake[Area]-CavMort[Area]-CavDeg[Area]-CavSFSLoss[Area])*dt \quad (6)$$

CavSFS = *Cavity Occupied by SFS* (Cavity): Arrayed Stock

CavSFSTake = *Cavity Taken by SFS* (Cavity): Based on Amount of SFSs

CavMort = *Cavity Tree Mortality* (Cavity): Same for all Cavities

CavDeg = *Cavity Degradation* (Cavity): Same for all Cavities

CavSFSLoss = *Cavity Loss in SFS Departure* (Cavity): Becomes Vacant

$$CavRCW[Area](t)=CavRCW[Area](t-dt)+(CavRCWTake[Area]-CavMort[Area]-CavDeg[Area]-CavRCWLoss[Area])*dt \quad (7)$$

CavRCW = *Cavity Occupied by SFS* (Cavity): Arrayed Stock

CavRCWTake = *Cavity Taken by SFS* (Cavity): Based on RCW Need

CavRCWLoss = *Cavity Loss in SFS Departure* (Cavity): Becomes Vacant

Foraging Index. To relate forest conditions into foraging quality, a foraging index was created for the model. Foraging habitat was a culmination of different factors in the forest. The Foraging Habitat Index for an area ranged from 0 to 1 and was determined by the area's number of older pines, density of older pines, density of older hardwoods, and amount of acreage undergoing conversion from slash to longleaf pine. These four different variables were translated into "Sub-Indexes" used to compute the Foraging Index equation. All four variables played a critical role in the quality of foraging habitat for the RCW. The model used the Foraging Index as a key variable in the RCW's

decision to disperse from and immigrate into an area and also to determined mortality rates of the RCW.

The four sub-indexes were developed to compute the Foraging Index. Each sub-index itself ranged from 0 to 1. The "Pine Density Index" took into account the density of the older age classes of longleaf and slash pines. Old-growth and mature age classes were rated higher than large pole age classes. Also, longleaf pines were rated higher than slash pines. Similar to the Pine Density index, the "Pine Tree Index" took into account the number of the older trees in each age class of longleaf and slash pine. Old-growth and mature age trees were again rated higher than large pole age trees. Likewise, longleaf pines were rated higher than slash pines. The "Hardwood Index" measured the density of pole age class hardwoods. The Hardwood Index had an inverse relationship with the density of the hardwoods. As the density of mature hardwoods increased, the Hardwood Index decreased. The "Fragment Index" accounted for the effect on habitat quality from the habitat fragmentation resulting from conversion of slash pine to longleaf pine. The Fragment Index used the percentage of the acreage in an area that was undergoing conversion to determine its rating. Like the Hardwood Index, the Fragment Index had an inverse relationship to the amount of acreage being converted.

The Foraging Index was computed by averaging the four different sub-indexes. The sub-indexes were weighted in the Foraging Index equation to stress specific variables. The weights themselves were also changeable. At extreme conditions for a sub-index value, the weight for the respective sub-index increased. This notion of variable weights incorporated the concept that every sub-index was important to the Foraging Index. Moreover, the notion also illustrated that one sub-index could greatly

lower the Foraging Index. The weights for the sub-indexes during normal conditions were as follows: Pine Density Index weight = 1, Pine Tree Index weight = 2, Hardwood Index weight = 2, and Fragment Index weight = 2. As extreme conditions occur, these weights can potentially reach 15. Extensive testing was performed on the parameters, curves, and equations used in the Foraging Index because of its high importance in the model. The Foraging Index equation index is shown next.

$$FI[Area]=((FFI[Area]*FFW[Area])+(FHI[Area]*FHW[Area])+(FPDI[Area] *FPDW[Area])+(FPI[Area]*FPW[Area]))/FWT[Area] \quad (8)$$

FI = Foraging Index (Pro): Combination of Indexes

FFI = *Foraging Fragment Index* (Pro*):* Measures Fragmentation

FFW = Foraging Fragment Index Weight (unitless): Accounts for Extreme Fragmentation

FHI = Foraging Hardwood Index (Pro): Measures Hardwood Encroachment

FHW = Foraging Hardwood Index Weight (unitless): Accounts for High Hardwood Density

FPDI = Foraging Pine Density Index (Pro): Measures Pine Density

FPDW = Foraging Pine Density Index Weight (unitless): Accounts for Sparse Densities

FPI = Foraging Pine Index (Pro): Measures the Number of Pines

FPW = Foraging Pine Index Weight (unitless): Accounts for Not Enough Pines

FWT = Total Index Weight (unitless): Summation of All Three Index Weights

Red-Cockaded Woodpecker Sector

The RCW was the largest and most detailed sector in the model. Under the spatial array layout of the model, each area was assumed to potentially be able to support

one RCW family group. A family group in the model consisted of a breeding male and female, their fledglings, and male helpers. Birds moved to and from areas depending upon the foraging conditions and family composition in the area. The RCW sector was broken out into six segments: Male RCWs, Female RCWs, Male Dispersal, Female Dispersal, RCW Breeding, and RCW Management. The model discretely represented the number of birds in each family unit due to the significance of a single bird to a small RCW population. The model incorporated integer amounts of birds that were born, died, and dispersed. The model did this by rounding the fractional amount of birds that resulted from RCW flow equations.

Males and Females. The model represented RCW males and females separately. For each gender, the model used an arrayed age class stock structure to represent the number of males and females in each family group within the area. The first age class stock was the fledglings. Fledglings either dispersed to another area, died, or matured into a one-year old adult in their family group. If a fledgling dispersed to a different area, it would be considered a one-year old adult in that new area. The adult age class stock was a two-dimensional array. The areas of the PWR made up the first dimension and the RCW adult age classes made up the second dimension. Two-dimensional arrays were used for the adult age class stocks to simplify the flow diagram. The model separated the adult age classes into five categories: 1 year olds, 2 year olds, 3 year olds, 4 year olds, and 5plus year olds. The 5plus year old age category included all birds that were five years old or older. The age breakout was chosen because the RCW life span in the wild is roughly five years.

Each age category in the adult age class stock was subjected to mortality losses, dispersion losses, immigration gains, and the aging-up in the adult age class. Also, RCWs could be gained by the management practice of translocating RCWs into an area. The model allowed for the translocation of one and/or two year old male and/or female RCWs. As with cavity plate restrictors and artificial cavity inserts, translocations of RCWs could play a vital role in maintaining and growing small RCW populations. The fledgling and adult mortality rate curves were based on the Foraging Index. Mortality rates increased as the Foraging Index decreased. The mortality relative to age class represented typical RCW mortality. Fledgling mortality was higher than adult mortality and female mortality was higher than male mortality. Also included in the fledgling mortality rate was the "Helper Effect." Helper RCWs in family groups assist in the raising of fledglings. The model decreased the mortality rate of fledglings when there was an increase in the number of helpers. The model's age-up process simply moved all the RCWs that did not disperse or die in an age category to the proceeding age category. The general equation for adult male age stocks is shown next.

$$\begin{aligned} &RCW\_M[Area,Age](t)=RCW\_M[Area,Age](t-dt)+(RCW\_MatureM[Area,Age1] \\ &+RCW\_AgeInM[Area,Age]+RCW\_TransM[Area,Age]+RCW\_ImmM[Area,Age] \\ &-RCW\_AgeUpM[Area,Age]-RCW\_MortM[Area,Age]-RCW\_DispM[Area,Age])*dt \end{aligned} \quad (9)$$

RCW_M = Number of Male RCWs in Area for the Age Class Specified (Birds)

RCW_MatureM = Male RCW Fledglings Maturing into RCW Adults (Birds)

RCW_AgeInM = Male RCW Adults Aging Up From Previous Age Class (Birds)

RCW_TransM = Male RCW Management Technique to Add Birds (Birds)

RCW_ImmM = Male RCWs From Other Areas (Birds)

RCW_AgeUpM = Male RCW Adults Aging Into the Next Age (Birds)

RCW_MortM = Male RCW Mortality Based on the Foraging Index (Birds)

RCW_DispM = Male RCWs Leaving Dispersing From Area (Birds)

RCW_DispM = Male RCWs Leaving Dispersing From Area (Birds)

Breeding. The RCW follows a cooperative breeding behavior. The model assumed from this behavior that the oldest male and female would be the breeding pair of the family. All other male RCWs in the group became helpers. The remaining females were forced to disperse to other areas. The birth rate of the breeding pair was dependent upon the age of the breeding pair. Older breeding pairs had a higher fecundity than younger breeding pairs. The maximum brood size in the model for a breeding pair was four nestlings. It was assumed that the nestlings were born in equal amounts for male and females.

Dispersal and Immigration. RCW movement from one area to another was a result of the foraging quality and/or family group compostion. In either case, modeling these phenomenons was quite complex. Movement from one area to another was dependent upon the geography and distance between areas. RCWs did not disperse far if they dispersed at all. Using the layout of the twenty areas on the PWR, a twenty by twenty matrix of dispersal likelihood rating between each area was developed. The ratings were called "Corridor Ratings," but were not considered pure movement corridors. Instead, the ratings represented corridors as probabilities of dispersal to different areas. Discretion was used for the classification of each rating according to the geographic layout of the PWR. Areas that were adjacent to each other were given a 1.0

Corridor Rating. Areas that were two areas away were generally given a 0.75 Corridor Rating. Areas that were three areas away were given either a 0.5 or 0.25 Corridor Rating. Areas that were typically not going to be dispersed into were given a 0.0 Corridor Rating. The Corridor Ratings are located in Appendix A. The immigration and dispersion potential equations were similar to the form of Foraging Index Equation 8. The equations that determined the area in which dispersing RCWs immigrated into used a series of "IF-THEN" logic statements. The immigration equation was set up to have dispersing RCWs immigrate into the area with the highest overall immigration potential.

The model devised a "Dispersal Potential" for each area, which was comprised of the overall "Corridor Dispersal Index," the acceptable "Cavity Index," and the Foraging Index. Each of these indexes in the Dispersion Potential was weighted to allow for higher priorities of indexes. The Dispersion Potential ranged from 0 to 1. The Corridor Dispersal Index, which ranged from 0 to 1, was a summation of the Corridor Ratings from one area to all of the other areas. Therefore, an area that was connected to many areas via corridors would have a greater chance for RCWs in that area to disperse. The number of acceptable cavities determined the Cavity Index for an area. The Cavity Index, ranging from 0 to 1, increased with the increase of acceptable cavities in an area. Zero cavities in an area corresponded to a zero Cavity Index rating and five or more cavities in an area equaled a 1 Cavity Index rating. A Cavity Index rating less than 0.2 would automatically force the dispersal of the RCWs in the area. The Foraging Index was also part of the Dispersal Potential. A Foraging Index lower than 0.4 would automatically force dispersal of the RCWs in the area. The model likewise devised an "Immigration Potential" for each area, which was comprised of the acceptable "Cavity

Index and the Foraging Index. Both of these indexes in the Immigration Potential were weighted to allow for higher priorities of indexes. The Immigration Potential ranged from 0 to 1. The Cavity Index for dispersion was the same one used for immigration in the model. Both the Dispersion Potential and Immigration Potential were used to determine RCW movement between areas. The two sexes have different reasons for dispersing and immigrating.

Male fledgling dispersal was solely based upon the Dispersal Potential for the area. If the fledglings stay in the family group, they became helpers. Adult male dispersal was dependent upon the dispersion potential of an area and number of males in its family group. If there were more than two males in a group, then the model automatically had the youngest adult males disperse until there were two adult males in the group. This action accounted for group size saturation, which was around six RCWs. Also, there was additional dispersion from an area that depended on the Dispersal Potential and presence of a breeding male. If a RCW adult was not the breeding male, then the chance for it to disperse was greater. After male RCWs dispersed, their decision of where to immigrate to was dependent upon the Immigration Potential for each area and the number of males in each area. The model had the male RCWs immigrating into the area with the highest Immigration Potential and did not have more than one RCW male. This reflected how saturated RCW groups exhibit territorial behavior. Presence of a breeding male in an area lowered its Immigration Potential. If a RCW male was unable to find an area that was acceptable to immigrate into, then it would die. The model computed the male RCWs that died from immigration.

Female fledglings dispersed automatically from an area as long as the breeding female still existed in the area. Female dispersal was dependent upon the Dispersion Potential of an area, if a breeding female existed in the group, and if a breeding male existed in the group. If there was more than one female in a group, then the model automatically had the youngest females disperse until there was only one female in the group. After a female RCW disperses, its decision of where to immigrate to was dependent upon if there existed a breeding female in the area, if there existed a breeding male in the area, and the Immigration Potential for each area. The model had female RCWs immigrating into the area with the highest Immigration Potential and did not have a breeding RCW female. If a female RCW was unable to find an area that was acceptable to immigrate into, then it would die. The model also computed the RCW females that died from immigration.

Model Validation Testing Methodology

The order of the sector testing was: trees, forest management, SFS, cavities, foraging index, and RCW. Reference modes were theorized for the different sectors of the model under different sets of conditions. General behavior of each sector was tested to conform to the respective reference mode. Family behavior tests were used to ensure that the modeling mechanisms adhered to their accepted behavior. Behavior anomaly tests were used to trace anomalous behavior back to the source within the model structure. Once general reference mode behavior was achieved, then boundary adequacy and extreme conditions tests were conducted on the model. Reasonable ranges on model input parameters were determined in these tests. Model adjustments were made when problems arose in achieving reference mode behavior and/or behavior of other realistic

situations. The results of these tests compared to their respective reference modes are displayed in the beginning of Chapter 4.

Model Parameter Sensitivity Simulation Methodology

Once the model achieved the general reference mode behaviors, then sensitivity tests were conducted on model parameters. The same order of sectors that was used to perform validity tests on the model was used for the sensitivity testing of the model. Upon completion of each parameter sensitivity test, the most logical parameter value was entered into the model. Descriptions of the variables tested along with their ranges tested in the model were described next for each sector. Sectors that were not sensitivity tested did not contain unknown parameters and were authenticated by the validity tests. Significant results from sensitivity testing and the accepted parameter values used for the model are shown in Chapter 4.

<u>Tree Tests</u>. The mortality rate curves for fire and carry capacity were adjusted to represent ideal fluctuations. Once the curves were drawn accordingly, then the mortality rate magnitude was adjusted to represent realistic growth behavior. For both the longleaf pine and slash pine, the seeding rate per pine tree was tested for reasonable growth behavior. The "Seeding Rate" refers to the number of seeds produced that germinated into seedlings. Also, the "Fire Protection" afforded to planted longleaf pines was tested to ensure a better growth. The "Hardwood Resprout Rate" for pole hardwoods was tested to ensure proper regrowth after fires.

<u>SFS Tests</u>. As with the trees, the mortality rate curves for the SFS were adjusted to represent reasonable growth behavior. The birth rate for the SFS was tested to compare overall growth behavior and population level of both SFS age classes.

Foraging Index Tests. The index curves for each sub-index were adjusted individually. The calibration of these index curves gives logical index output for the given input variables. Likewise, the weight curves that account for extreme conditions were calibrated to give reasonable output for the foraging index. The "Large Pole Foraging Rating" downgraded the foraging quality of large pole age class pines as a percentage of the optimal older age classes' foraging quality. The foraging rating of the large pole age classes for pines was tested to check for variations in the Foraging Index. As with the Large Pole Foraging Rating, the "Slash Pine Foraging Rating" downgraded the foraging quality of slash pines as a percentage of the longleaf pine foraging quality. The foraging rating of the slash pine age classes was tested to check for variations in the Foraging Index.

Cavity Tests. The amount added to the mortality rate of cavity trees was tested to check for increased mortality of RCWs due to cavity tree loss. The number of cavity-enlarging birds in an area of the model was tested to check for the increased mortality of RCWs due to cavity loss. The "Cavity Construction Rate" curve was modified to test for increased RCW occupied cavities. The SFS "Take Rate" curve for vacant cavities was adjusted to represent theoretical SFS occupancy of acceptable cavities.

RCW Tests. The birth rate curves for the RCW were adjusted to reflect actual brood sizes for the combined age of the RCW breeding pair. Mortality rate curves for male and female RCWs were adjusted to reflect theorized RCW growth behavior under specified conditions. Once the shape of the curves was determined, then the mortality rate magnitude was adjusted to represent realistic growth behavior for the RCW population. Also tested was the effect that changing the female mortality rate had on the

RCW population. The effect that male RCWs have on the dispersion and immigration of other males and females was tested to acquire smooth realistic RCW population changes. The index weights for corridors, cavities, and foraging that made up the dispersal potential and immigration potential were tested to determine proper weight calibration. The index weight values were ranged from 1 to 5 in various combinations until proper calibration was determined.

Methodology of the Combination of Management Techniques

Upon the completion of the sensitivity tests, the model was ready to simulate different management scenarios. Simulations were run first to establish the best forest management techniques. The techniques used were prescribed burning, hardwood thinning, pine thinning, and herbicide application. Conversion from slash pine to longleaf pine was not simulated at this time. The focus on conversion management was simulated later on during testing. Various forest management combinations were tested to attain the goal of maximizing the Foraging Index's rate of increase and steady-sate level. Forest management testing simulations used the same respective areas on the PWR that were used in the reference mode and sensitivity tests. Alternative forest management combinations were outlined from the results.

The forest management alternatives were then simulated with combinations of direct RCW management practices. From the RCW management simulations, RCW management alternatives were outlined from the results. The RCW management alternatives were then used in conjunction with various conversion management options. From the results of all the management simulations, ecosystem management combinations can be recommended that best suit the customer's RCW management

goals. As with the rest of the model, management techniques were structured in an array format. The possibility of engaging select management practices in certain areas leads to a multitude of possible management combinations. To avoid running numerous similar simulations, the scenarios ran were feasible combinations of management practices.

Forest Management

Prescribed Burning. The first management technique tested was the frequency of prescribed burns. Simulations were looking to maximize pine growth and minimize hardwood growth. Burning schedules were segregated so different parts of the PWR get burned in different years.

Hardwood Thinning. The next management technique tested was hardwood silviculture thinning using different burn intervals. The simulations were conducted at different harvest intervals and amounts. The tests looked to minimize hardwood growth. As with burning, the areas that were thinned varied year to year.

Pine Thinning. Pine silviculture thinning was tested next using different burn intervals. As with hardwood thinning, the simulations were conducted at different harvest intervals and amounts. Dissimilar to hardwood thinning, the tests looked to maximize the older pine age classes' growth rates. Therefore, only the small pole and large pole age classes were thinned. Different harvest areas were thinned each year.

Herbicide Application. Herbicide application management was tested with and without burning. Tests were simulated at different application intervals. The tests looked to minimize hardwood growth with the least amount of herbicide applications. Areas receiving herbicide each year differ to allow for management variation.

RCW Management

Alternatives consisting of various forest management practices were used in conjunction with different RCW management practices. RCW management practices include the following: cavity restrictor plate installment, artificial cavity installment, SFS capture, and RCW translocation. In addition, various slash pine to longleaf pine conversion rates and amounts were simulated throughout the PWR areas. All of the simulation results are summarized in a results table at the end of Chapter 4.

Cavity Restrictor Plate. The first RCW management technique tested was cavity restrictor plate installment. Restrictor plate installment to cavities was tested at various amounts and intervals. Each year, different areas had restrictor plates installed. The five-year rotating installment schedule had restrictor plates installed in four areas each year. When used, restrictor plates were installed in equal numbers to the areas that they were installed. Simulations were exploring to see if restrictor plate installment increased the RCW population.

Artificial Cavities. The next RCW management technique tested was the amount and frequency of artificial cavity installment. Each year, different areas had artificial cavities installed. The five-year rotating installment schedule had artificial cavities installed in four areas each year. When used, artificial cavities were installed in equal amounts to the areas that they were installed. Simulations were exploring for cavity installment rates that increased the RCW population by creating new groups in areas previously vacant of RCWs.

SFS Removal. SFS capture and removal was the next management technique tested. When implemented, SFS removal occurred annually in all areas for the specified

capture percentage. Simulations were exploring to see if SFS removal increased the RCW population.

RCW Management Combination. To simulate an intensive management strategy, cavity restrictor plate installment, artificial cavity installment, and SFS removal were all used together in conjunction with a five-year burn interval. The simulation explored the cumulative effects of using multiple management techniques.

RCW Translocation. RCW translocations are the most direct way to assist small RCW populations. Simulation tests released a number of RCWs in specific areas of the PWR. The amount, pair age, and area released all varied. Translocations were conducted in areas that are void of RCW family groups. Translocations were performed in areas with at least one male and female RCW. The simulations were searching for new family unit creation and growth in areas without RCW groups.

Slash to Longleaf Pine Conversion. The most critical management technique for this thesis effort was converting from slash to longleaf pine. The conversion setting, interval between conversions and acreage converted, was varied during the simulations. Conversion settings for each area varied dependent upon the current status of each area's forest composition. Simulations explored the short and long-term effects on the PWR RCW population by using various conversion settings in combination with different RCW management alternatives.

4. Data Analysis and Results

Reference Modes

A total of eleven reference modes, consisting of main model variables, were used to guide the development of the model. The reference modes denoted the critical components and dynamics of the ecosystem being modeled. If the model represented actual ecosystem functioning, then the behavior of the model corresponded to the reference modes' theorized behaviors. Each reference mode is discussed, displayed, and compared with its respective model output. Relative simulation information is shown in each figure's bottom right-hand corner. Model trace labels are shown in each figure's bottom left-hand corner. Definitions for the tree age class traces are in the Appendix A glossary. The model output for the tree age class traces had a jagged appearance for two reasons. First, immediately after a burn, there was a loss of trees relative to the fire intensity. Second, due to the conveyor-based age class stocks, groups of trees matured into their ensuing age classes at the same time. Thus, the density level of the age class that the trees left immediately dropped while the receiving age class level instantly rose.

Longleaf Pine. The reference mode behavior for the density of the different longleaf pine age classes was theorized to show the transition of dominance in age classes. This phenomenon displayed the growth from a new forest to an old-growth forest. The initial conditions used in reference mode comparison reflected the age structure of a young forest. Likewise, simulating a clear-cut of the older age classes in an area displayed the same forest re-growth behavior. Reference mode behavior was replicated and shown in Figures 30 and 31.

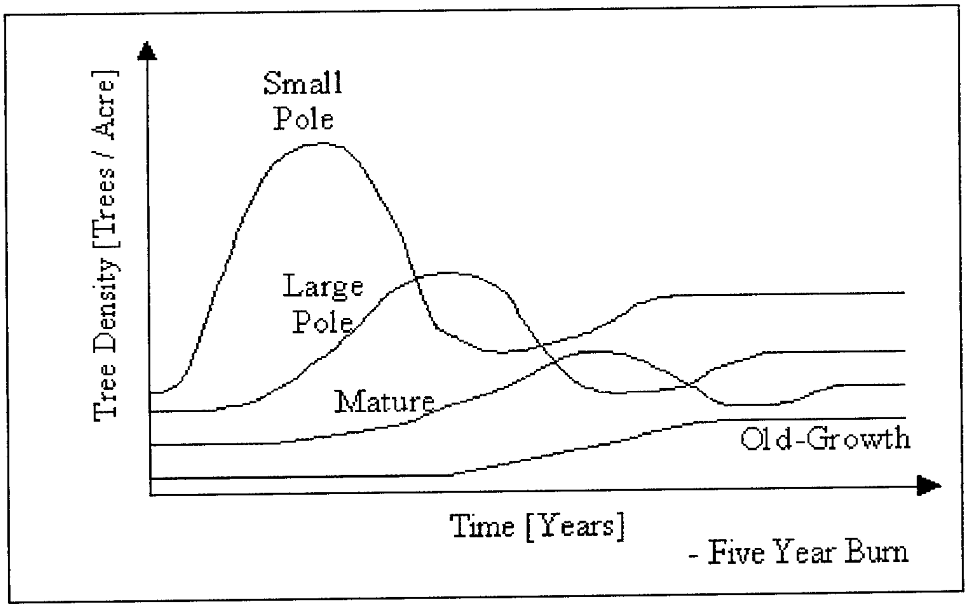

Figure 30: Area Longleaf Pine Reference Mode

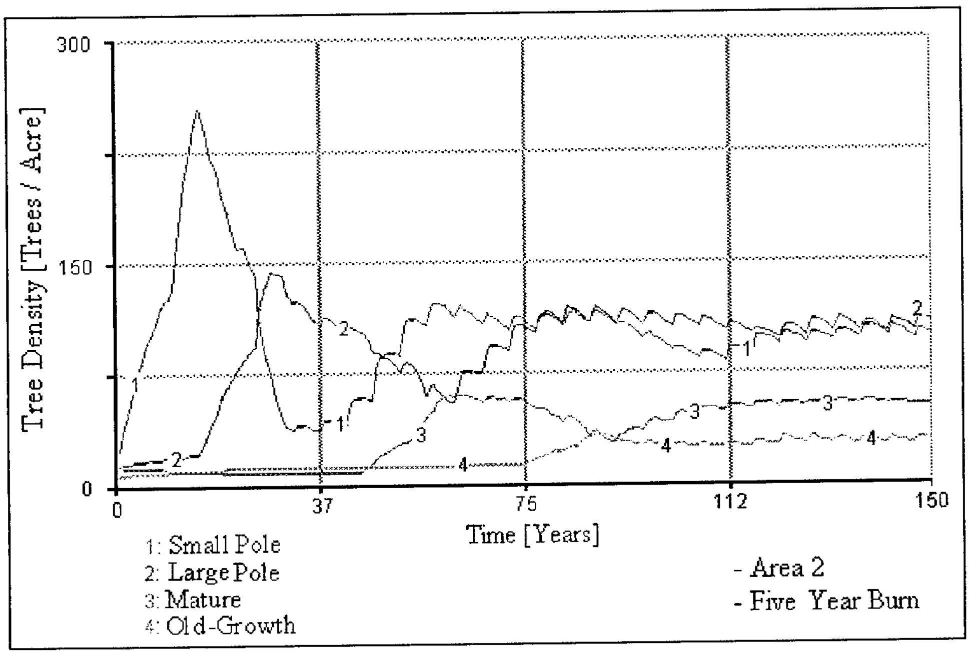

Figure 31: Area Longleaf Pine Baseline Output

Slash Pine. The reference mode behavior for the density of the different slash pine age classes was also theorized to show the transition of dominance in age classes. The reference mode comparison's initial conditions used an area on the PWR with a slash

pine density structure representative of an area planted with off-site slash pine.

Reference mode behavior was replicated and shown in Figures 32 and 33.

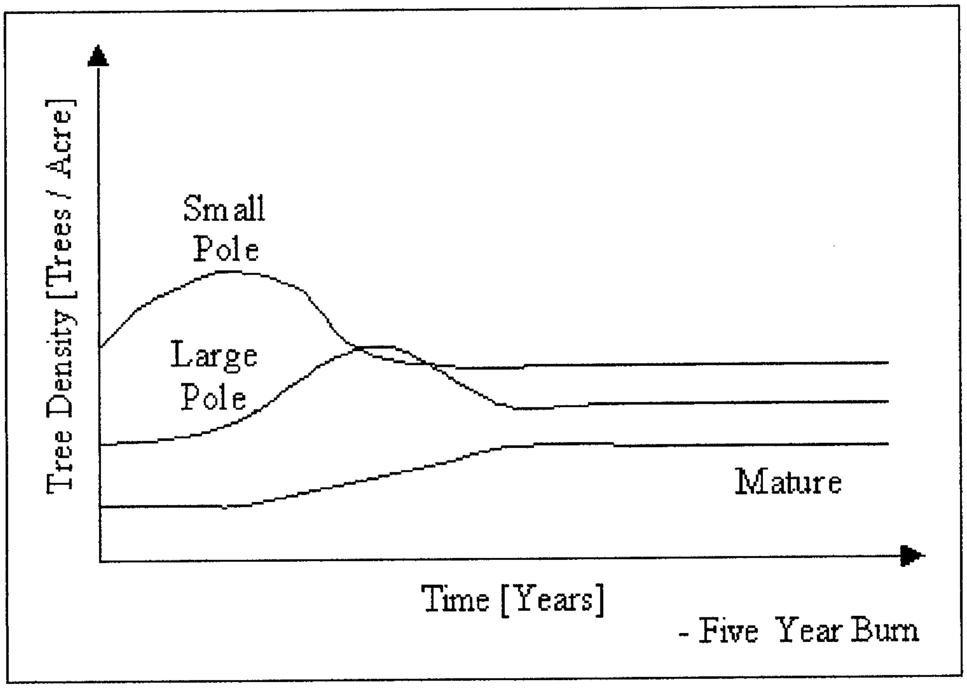

Figure 32: Area Slash Pine Reference Mode

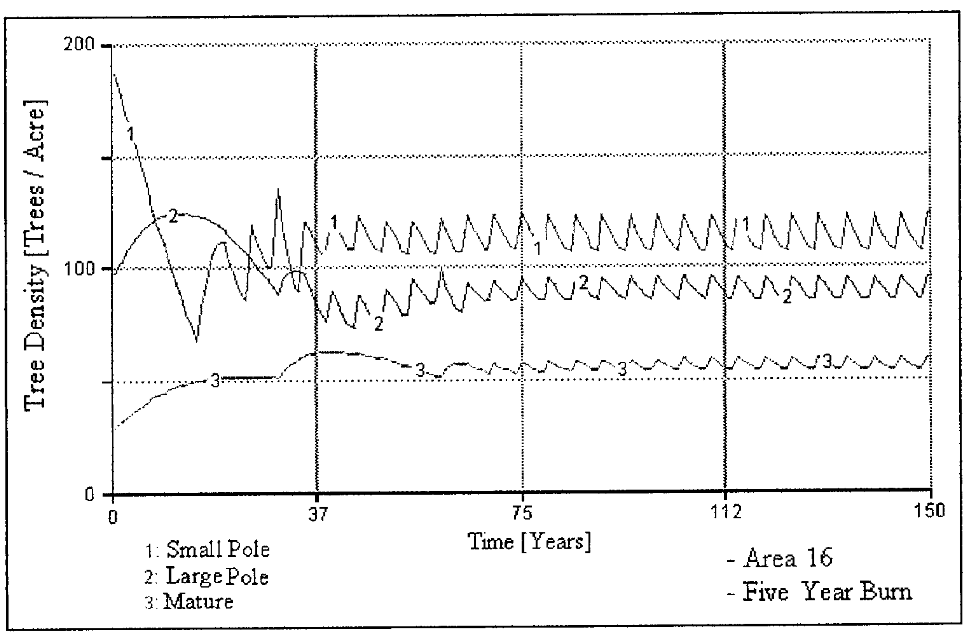

Figure 33: Area Slash Pine Baseline Output

Hardwoods. The reference mode behavior for the density of the two hardwood age classes was theorized to show repressive effects of fire on hardwoods. The reference mode comparison's initial conditions used an area on the PWR that represented a high hardwood density. Reference mode behavior was replicated and shown in Figures 34 and 35.

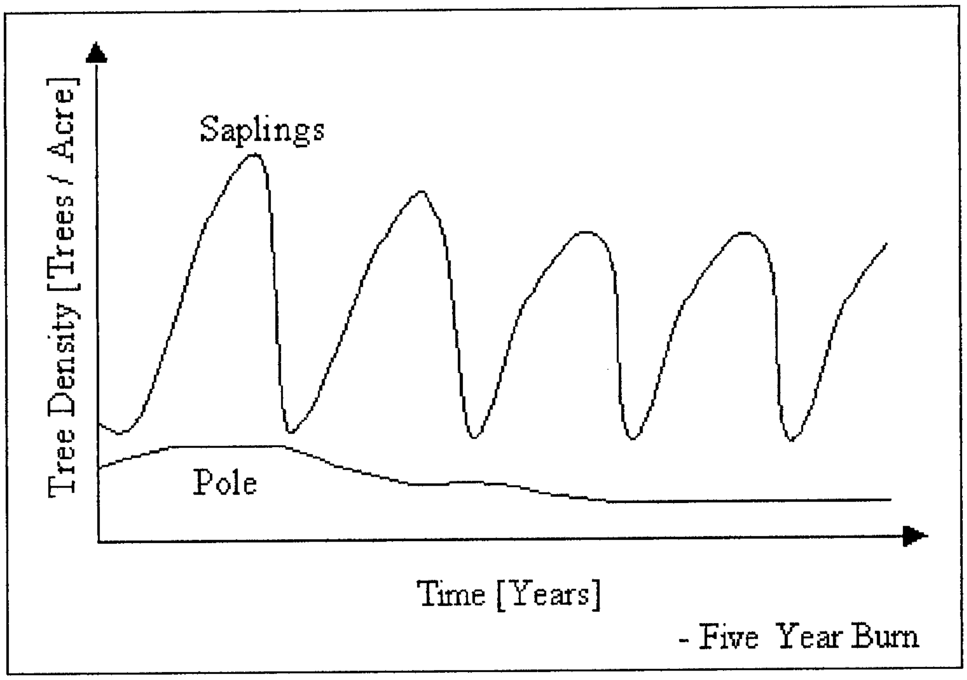

Figure 34: Area Hardwood Reference Mode

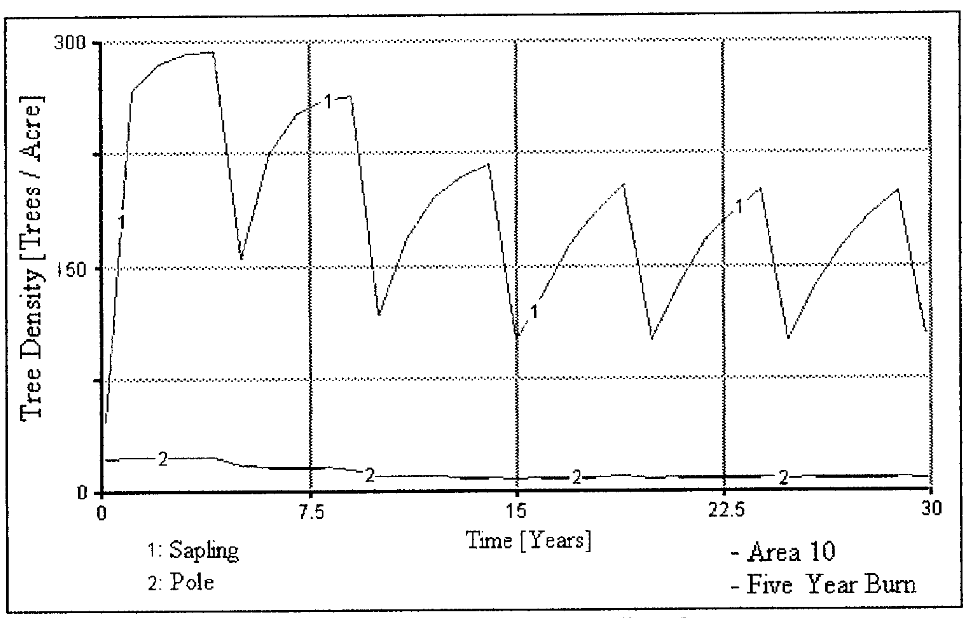

Figure 35: Area Hardwood Baseline Output

Southern Flying Squirrel. The reference mode behavior of the SFS population was theorized to show how the SFS was dependent on the density of older hardwoods. The reference mode comparison's initial conditions used an area on the PWR that represented a high hardwood density, therefore the area contained SFSs. The SFS population trace jaggedness was due to the direct dependence of SFSs on older hardwoods. Reference mode behavior was replicated and shown in Figures 36 and 37.

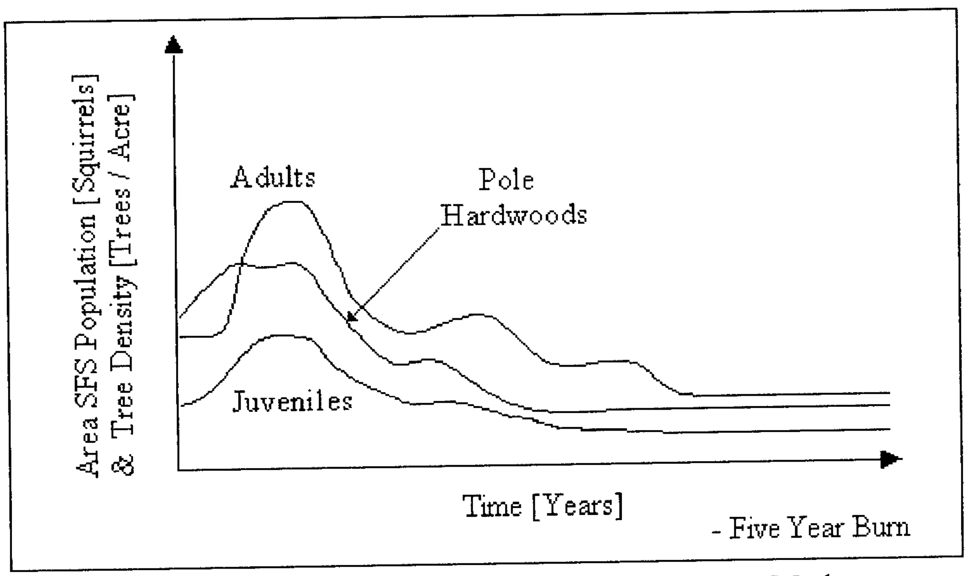

Figure 36: Area Southern Flying Squirrel Reference Mode

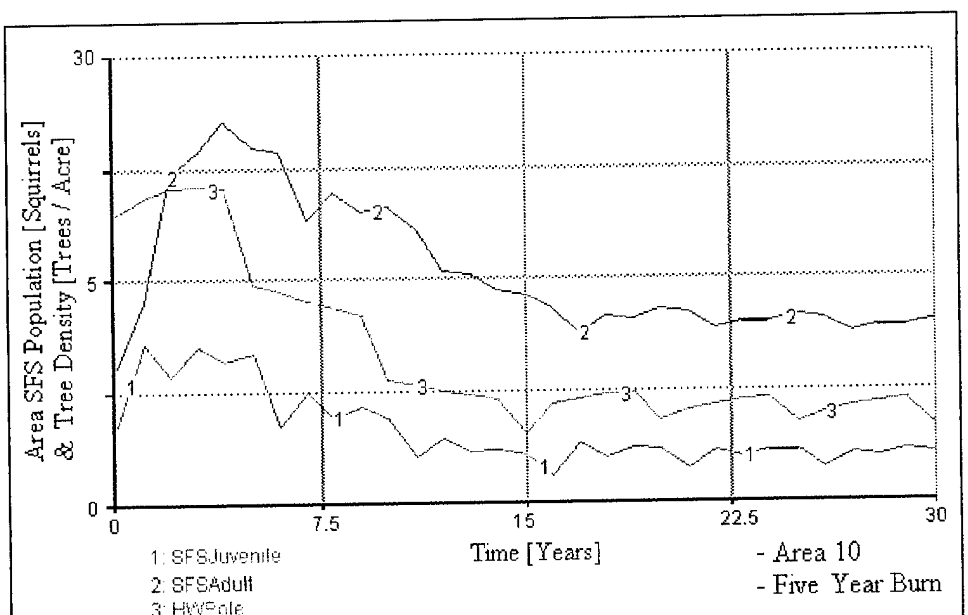

Figure 37: Area Southern Flying Squirrel Baseline Output

Fire. The reference mode behavior of fire was theorized to show how the frequency of fire affected the fire intensity and the fire effect variable. The model's fire variables and fire structure logic were defined in Chapter 3. Reference mode behavior was replicated and shown in Figures 38 and 39.

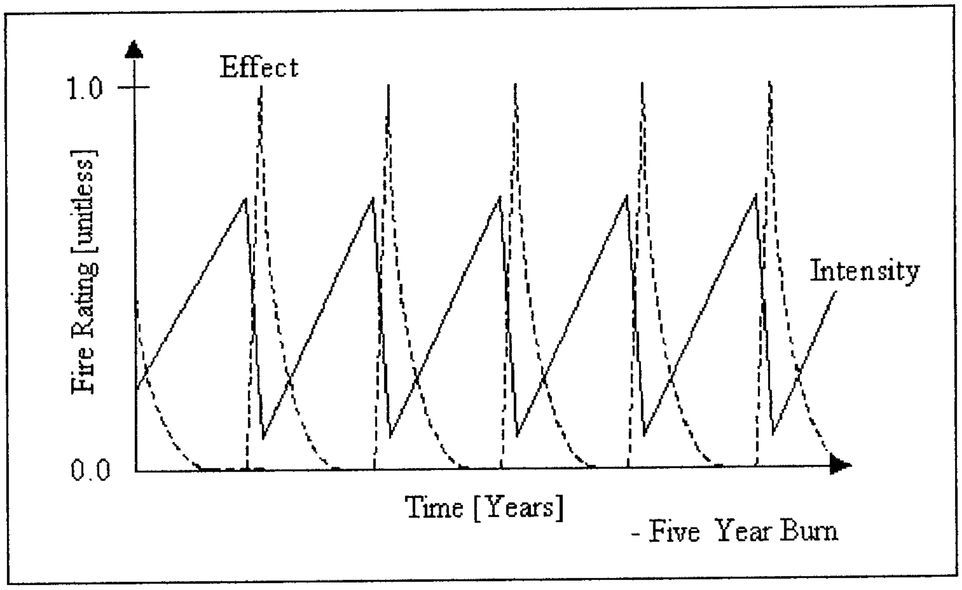

Figure 38: Area Fire Reference Mode

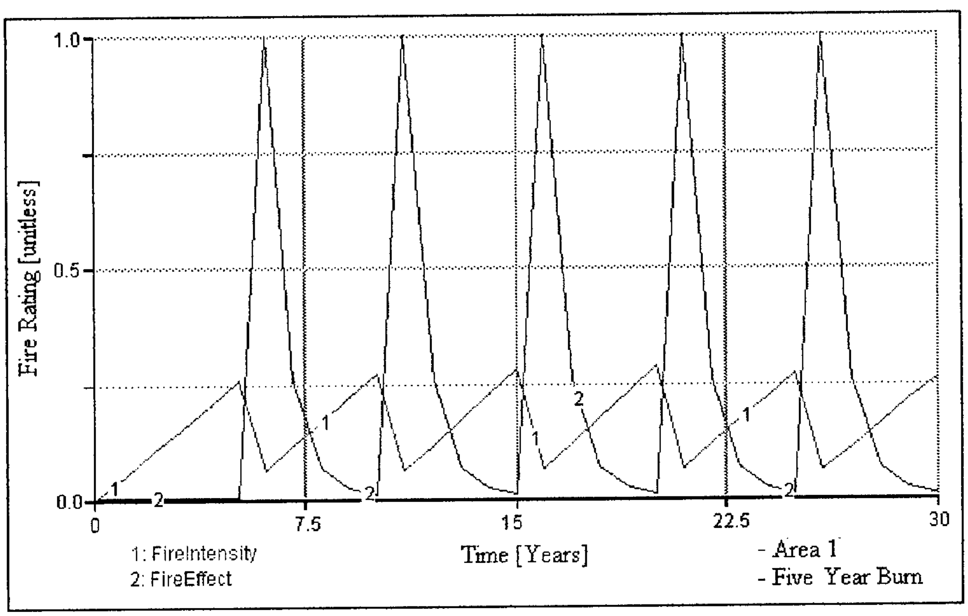

Figure 39: Area Fire Baseline Output

Acreage. The reference mode behavior of acreage conversion was theorized to show how land was converted from slash pine acreage to conversion acreage, and then finally into longleaf acreage. The conversion rates for each area were set at ten acres converted every ten years. Reference mode behavior was replicated and shown in Figures 40 and 41.

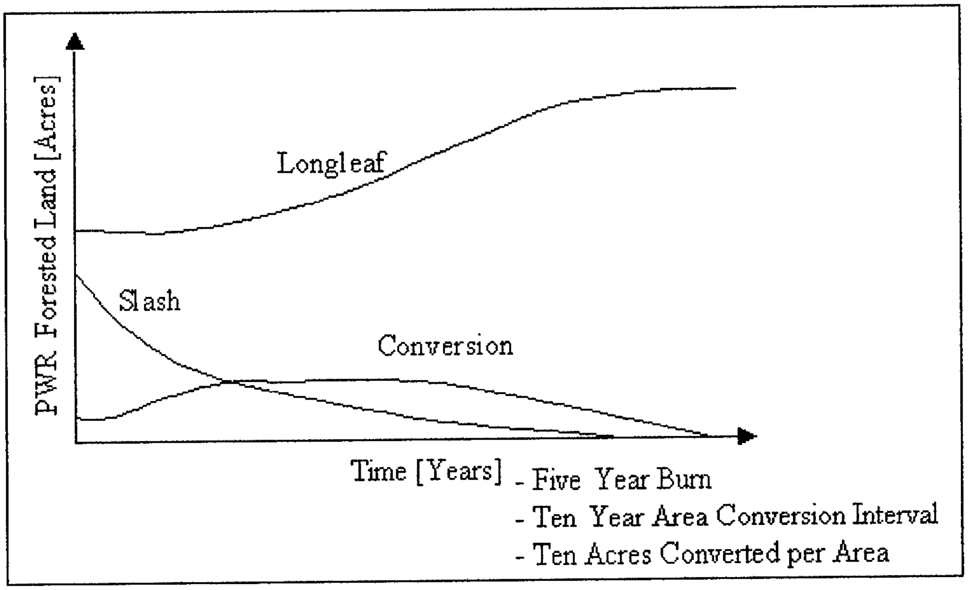

Figure 40: Poinsett Weapons Range Acreage Conversion Reference Mode

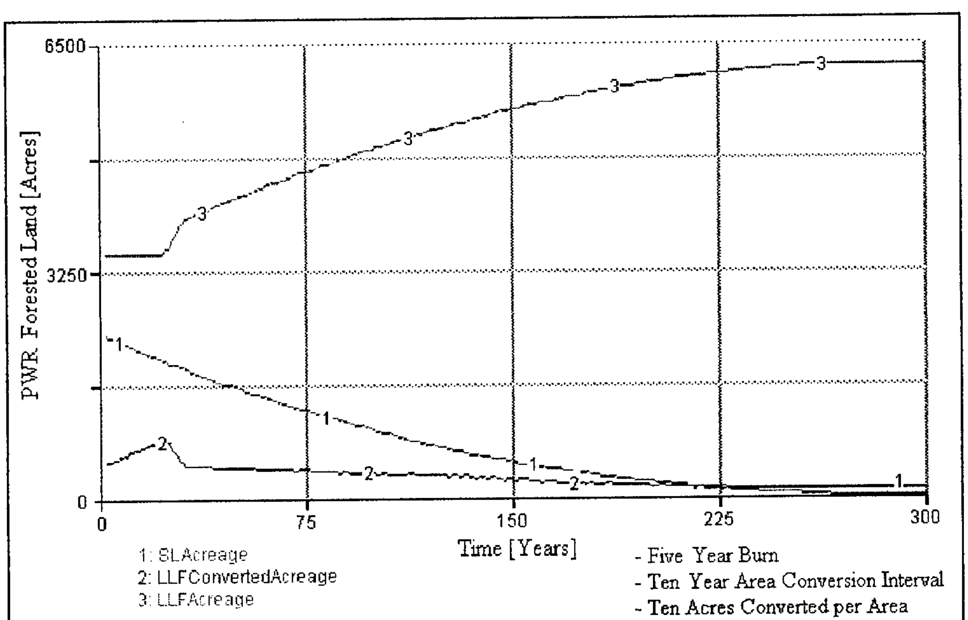

Figure 41: Poinsett Weapons Range Acreage Conversion Baseline

Foraging Index. The reference mode behavior of an area's foraging index was theorized to show an increase in an area's foraging habitat quality as the forest develops under a five-year prescribed burning interval. Thereafter, a second reference mode showed the effect on the foraging index by also incorporating slash to longleaf pine conversion. An area consisting mostly of slash pine acreage was used for reference mode comparison. Reference mode behavior was replicated and shown in Figures 42 and 43 and in Figures 44 and 45. Conversion increased the long-term steady-state index level.

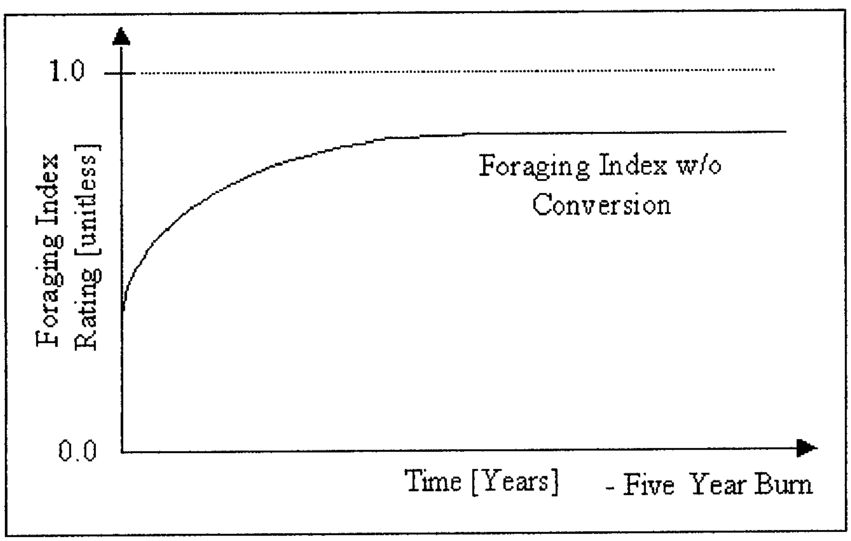

Figure 42: Area Foraging Index w/o Conversion Reference Mode

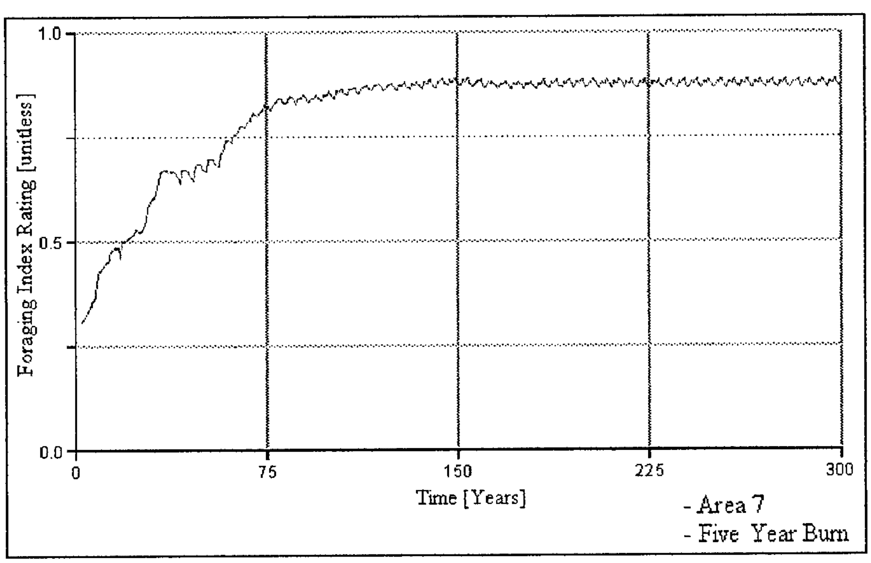

Figure 43: Area Foraging Index w/o Conversion Baseline Output

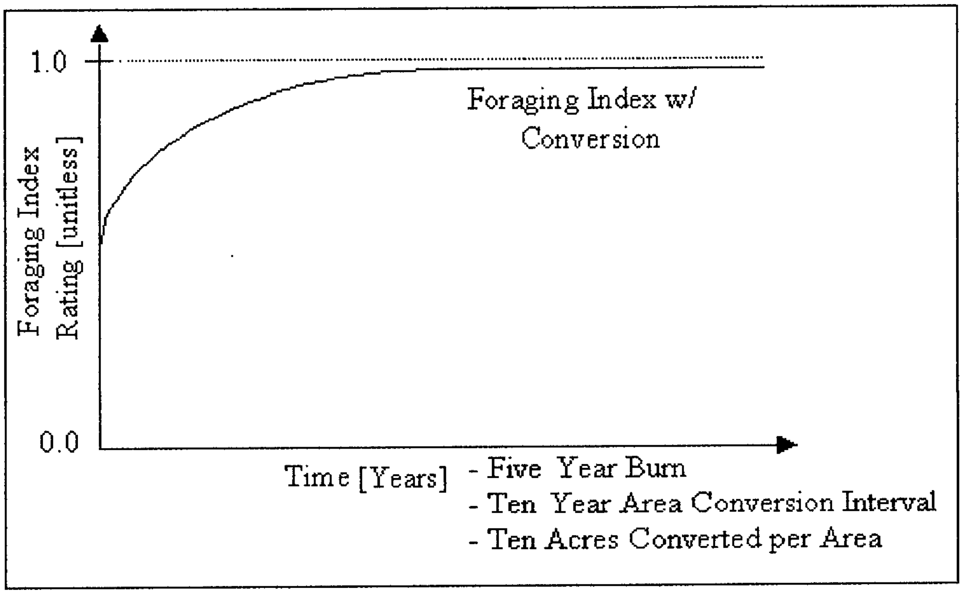

Figure 44: Area Foraging Index w/ Conversion Reference Mode

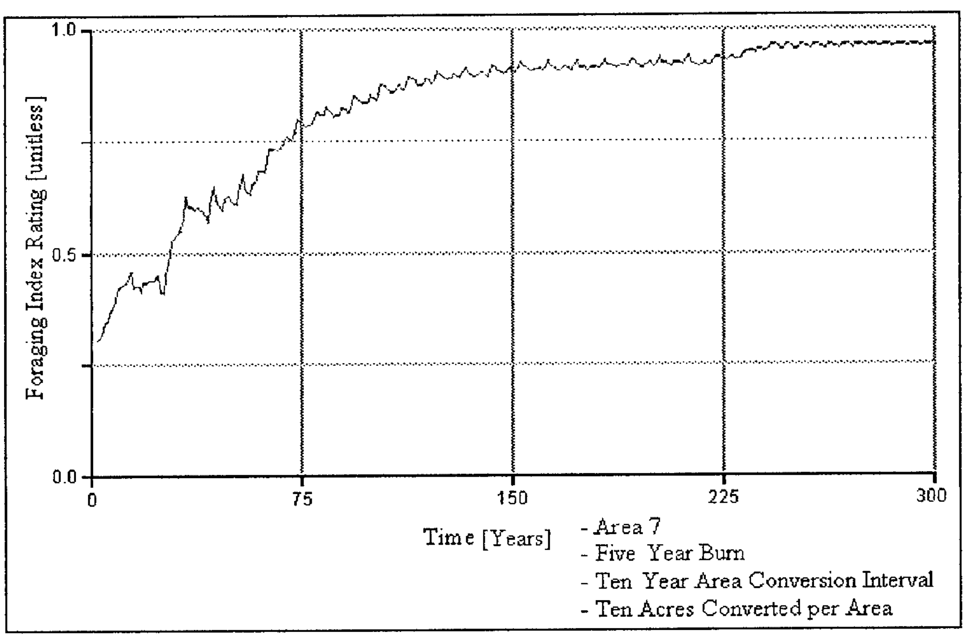

Figure 45: Area Foraging Index w/ Conversion Output

Cavities. The reference mode behavior of cavity status was theorized to show the dynamics of cavity occupation. Upon the loss of a RCW or SFS, the cavity they occupied became vacant. The proceeding year, depending on the area population status, a RCW or SFS reoccupied the vacant cavity as shown in the reference mode. The distinct fluctuating trace outputs were due to discrete changes in cavity status. Reference mode behavior was replicated and shown in Figures 46 and 47.

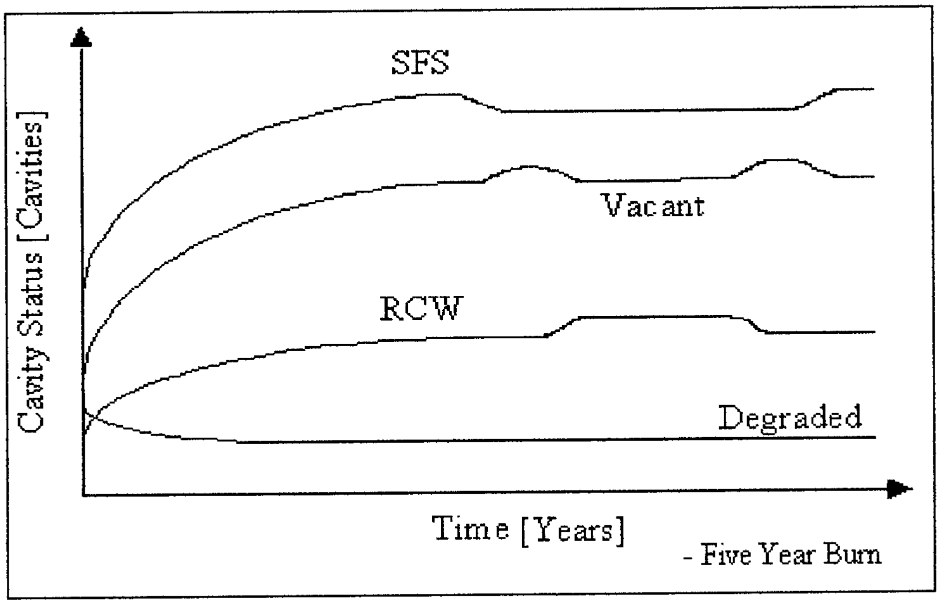

Figure 46: Area Cavity Status Reference Mode

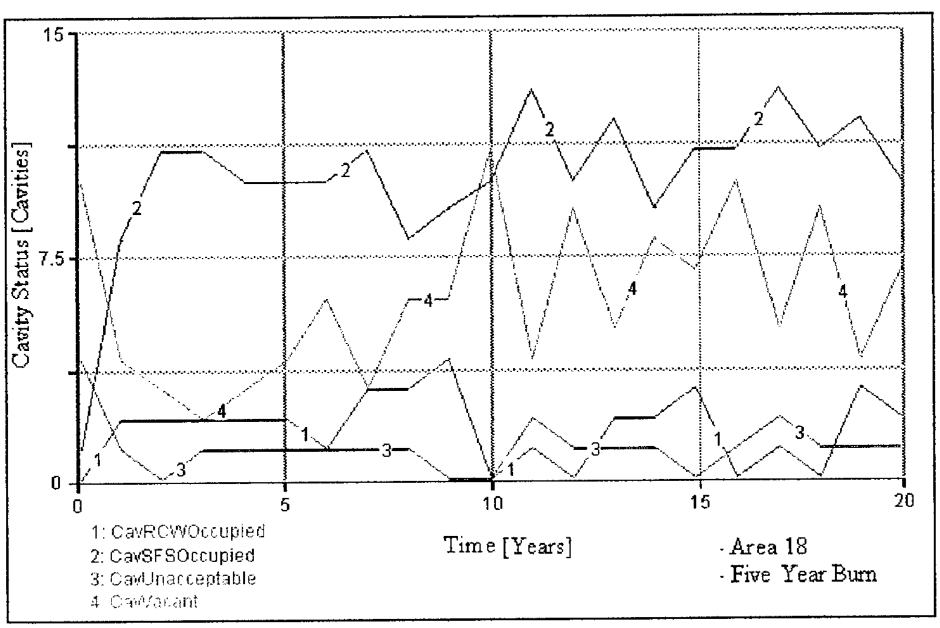

Figure 47: Area Cavity Status Baseline Output

Red-Cockaded Woodpecker. The reference mode behavior of the PWR RCW population was theorized to show the population levels in the future using only a five-year interval for prescribed burning. Males were assumed to be in greater numbers than females to reflect actual group gender ratios due to the RCW's cooperative breeding nature. It was assumed that the population would level off once the PWR RCW group capacity was reached. A second reference mode showed the effect on the RCW population by incorporating management practices such as: artificial cavity box and restrictor plate installation, SFS removal, and slash to longleaf conversion. As with the cavities, the distinct fluctuating RCW trace outputs displayed resulted from the discrete modeling of individual birds as well from the RCW's dynamic behavior within groups. Reference mode behavior was replicated and shown in Figures 48 and 49 and in Figures 50 and 51. The application of management practices increased the PWR RCW population level.

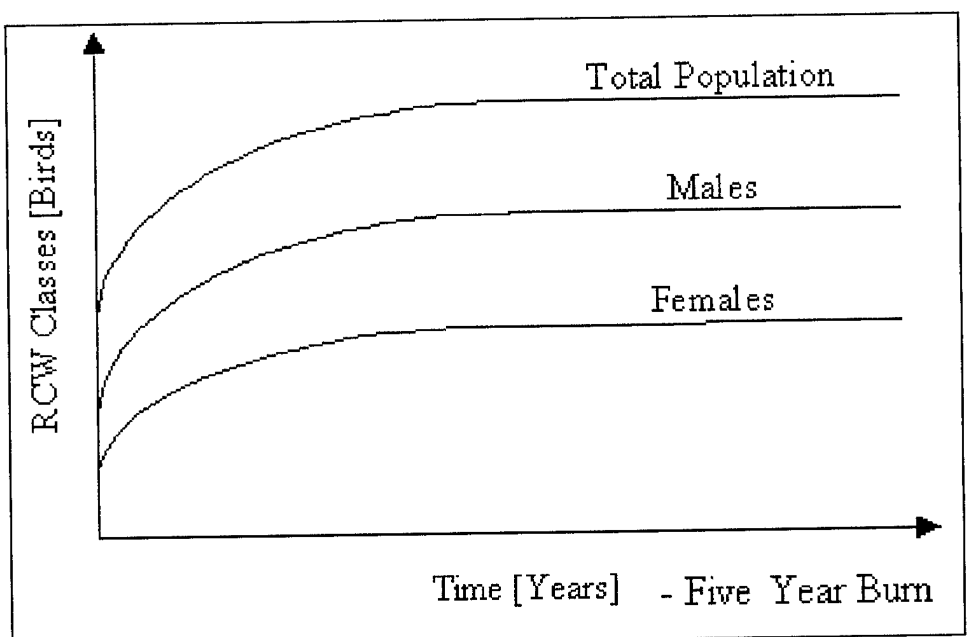

Figure 48: Poinsett Weapons Range Red-Cockaded Woodpecker Population Reference Mode

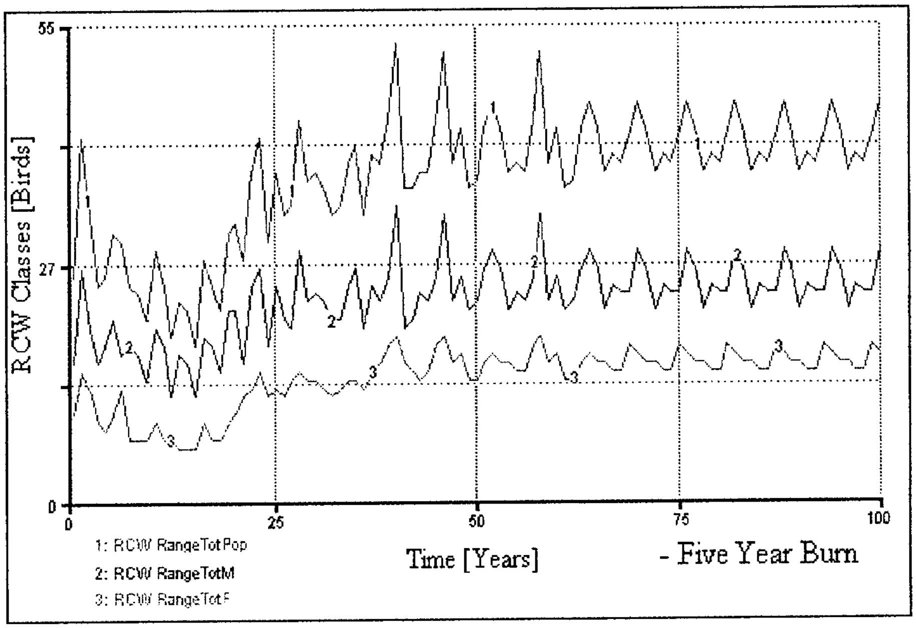

Figure 49: Poinsett Weapons Range Red-Cockaded Woodpecker Population Baseline Output

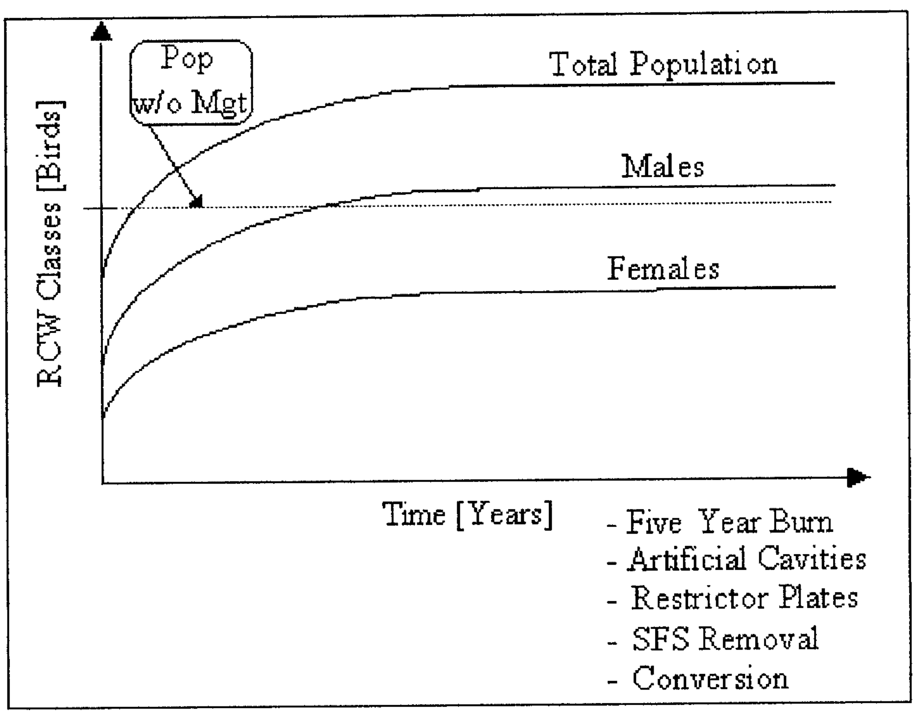

Figure 50: Poinsett Weapons Range Red-Cockaded Woodpecker Population with Management Reference Mode

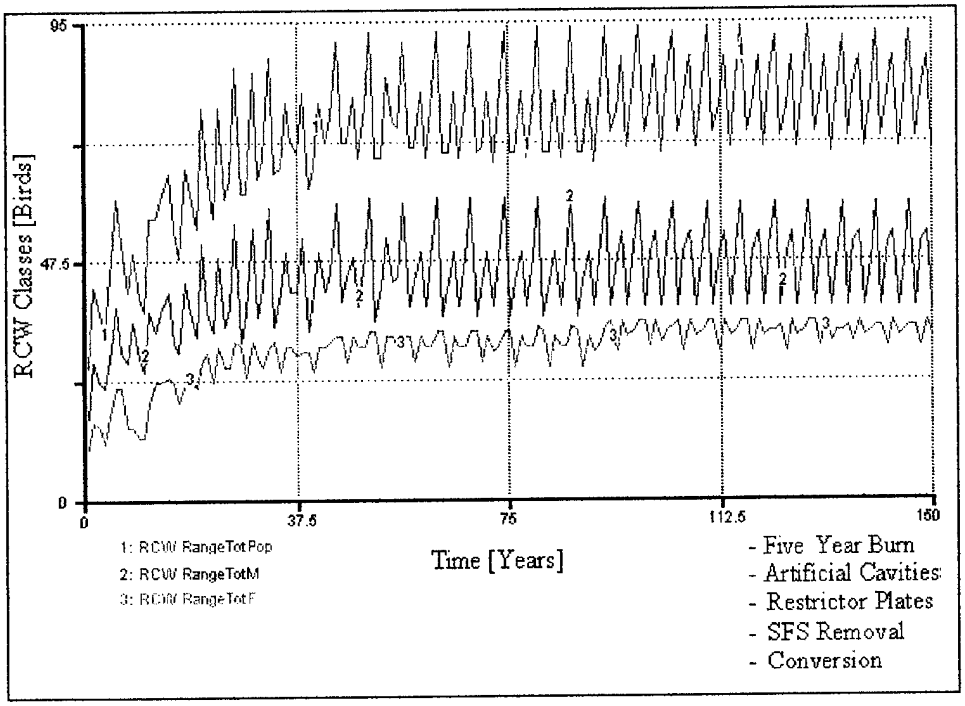

Figure 51: Poinsett Weapons Range Red-Cockaded Woodpecker Population with Management Output

All eleven reference modes were reproduced by the model for the given baseline conditions. It can be concluded that the basic mechanisms driving the model created the eleven desired reference modes. Therefore, it appeared that the overall dynamic hypothesis of the PWR ecosystem had been successfully modeled. The various tests used to attain reference mode behavior during model construction are outlined next.

Validation Testing

Family Behavior Test. There are common types of model structures used in system dynamics modeling. Similar model structures that display comparable types of behavior are know as families. Models that incorporate these common family structures should display the behavior representative of the family. Various combinations of family structures were used to develop the PWR model.

The tree sectors used parts of "S-Shaped Growth" and "Main Chain" families. S-Shaped growth uses a combination of exponential growth equations, which are adjusted to reach a target level. The trees exponential growth was brought under control by increased mortality at higher densities. Main Chain structure uses a series of stocks to show transitional movement of units. The trees were divided up into age classes to show the growth of the trees as the forest transitioned into an old-growth steady-state. The Fire Effect variable used a step input that diminishes exponentially. This was an example of behavior seen in the "Exponential Smoothing" family. "Co-Flow" families show stock levels that are directly dependent upon the value of another stock. The SFSs represented a Co-Flow behavior dependent upon the density of older hardwoods. The RCWs showed behavior reminiscent of "Damped Oscillation" family. In this family's behavior, competing parallel stocks influence each other's flows, which brings the system into an oscillating behavior. The dampening of the system eventually led the stocks into a dynamic steady-state condition. The RCWs behavior was dependent upon Foraging Index behavior. Initially, the stock values for the RCWs were oscillating according to the changing Foraging Index. The leveling of the Foraging Index to a dynamic steady-state acted as a partial damper for the RCW population. The damper brought the RCW

population to a dynamic steady-state in which the annual fluctuations in the RCW population started to consistently repeat. The PWR model incorporated complex model structures. These structures were broken-down into the standard system dynamics family structures explained above. The relevant family behaviors were replicated during those tests.

Behavior Anomaly Test. Behavior anomaly tests were used throughout the construction of the model. After a sector of the model was completed, simulations were run on relevant sector variables to test for appropriate behavior. The simulations often showed anomalous behavior. This behavior was then traced back to the source in the model and corrected. During model construction, the behavior anomaly test was used often in the debugging of RCW dispersal and immigration. Graphical output from the model showed that the birds that dispersed did not add up to the birds that would immigrate in a given year. The reason for the discrepancy was traced back to logic errors in the dispersal and immigration equations. Upon correcting, annual totals for RCW movements were equal.

Sometimes anomalous behavior provided insight into proper, yet unrealized, theoretical system structure. This happened during model construction when the conveyor tree age class behavior seemed not to show proper transition between classes due to abrupt growth changes. Upon further inspection, it was realized that the structure was behaving correctly. The modeler was exploring initial growth amounts of seedlings as they progressed through the age classes. The sudden jumps in age class densities were due to other seedlings that were regenerated by existing older trees. Behavior anomaly tests were often used to validate basic model structure during construction.

Boundary Adequacy Test. The model was constructed to address the research objectives and problem statement. In doing this, the scope of the model was determined to properly focus on relevant components of the PWR ecosystem. The boundary adequacy test was done to ensure that only relevant components that affected the RCW were modeled. For example, the initial influence diagram for the model included snag trees. During the literature review, it was determined that snags have positive and negative effects, that when combined, have a minimal effect on the RCW. Another example of a boundary adequacy test was limiting the scope of the SFS population. The model simply estimates the two SFS age totals by the presence of older hardwoods. The SFS population dynamics is more complex, about as extensive as the RCW's. But the emphasis for the modeling effort was the RCW, not the SFS. Obviously, there are sectors in the model more critical than others. However, all variables in the model have some impact on the RCW population. If removed from the model, the variables non-impact would be detected.

Extreme Condition Test. As the model was built, extreme realistic values for different parameter values and initial stock levels were entered into the model. If properly constructed, the model showed plausible behavior for the given conditions. If not, then additional structure and logic was developed for the model, or a limit for the model's effective range was set. An example of an extreme condition test applied to the model was suppressing fire, similar to situations that have occurred in the southern pine forests during the last century. When fire was suppressed from the PWR, the hardwoods began to dominate the forest as the pines eventually were choked out. The outcome of the fire suppression extreme conditions test is displayed in Figure 52.

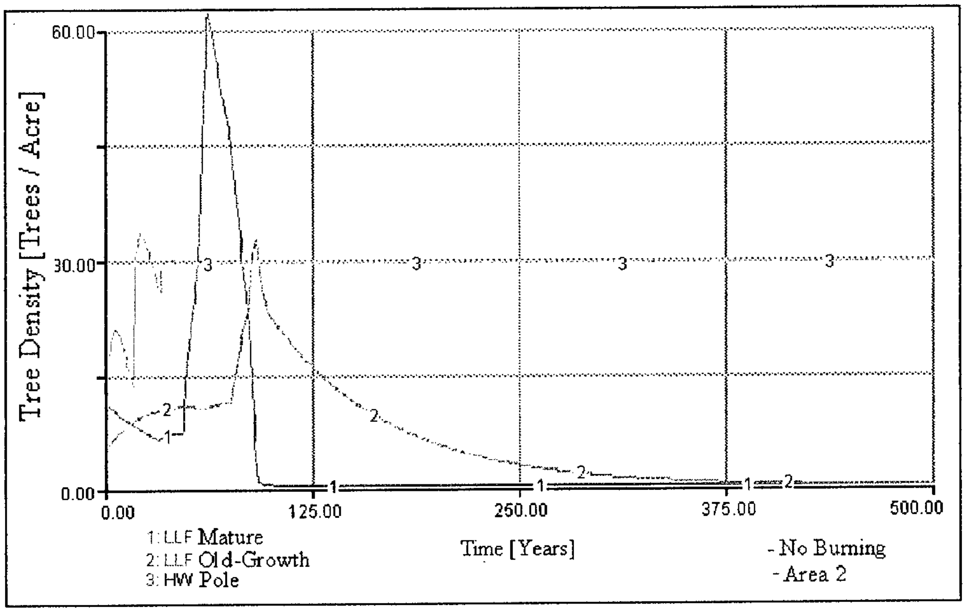

Figure 52: Fire Suppression Extreme Condition Test

Sensitivity Tests and Final Parameter Values

Varying the value of model parameters through extreme ranges determines the parameter's significance and the model's sensitivity to the parameter. Once identified, sensitive parameters were closely scrutinized to reach accurate input values. When applicable, sensitivity tests were performed on variables in the areas that were used to show the variable's reference mode. The variables that were sensitivity tested for each sector are discussed next.

Pine Tree Fire Mortality Rate Magnitude. The "Fire Mortality Rate Magnitude" was adjusted from 0.25 to 1.00. The fire frequency was held constant at a five-year prescribed burn interval. The magnitude refers to the percentage of trees killed by fire for the given fire intensity. Hence, at 0.25, 25% of the trees died that would normally died

from the corresponding fire intensity. At 1.0, all of the trees died for the given fire intensity. The different longleaf and slash pine age classes were all fairly unaffected by the changes in the mortality magnitude. The results were similar when the fire frequency interval was lengthened. The final value set for the Fire Mortality Rate Magnitude was 0.5.

Pine Tree Seeding. The annual "Seeding Rate" (number of seedlings produced) per tree was ranged from 10 to 50 for the slash and longleaf pine. The fire frequency was held constant at a five-year prescribed burn interval. The results showed that the seeding amount slightly affected the long-term steady-state levels for different pine tree age classes. Smaller seeding amounts produced lower steady-state levels. Also, the older age classes were affected the least by the seeding amount. The difference was minimal when the seeding level was increased past 30 for longleaf pines. For slash pine, the changes in the Seeding Rate barely affected the age classes' steady-state levels. The output from the age classes was similar to age densities in southern pine forests. Therefore, the Seeding Rate was set at 30 and 25 respectively for longleaf pine and slash pine. The sensitivity of small pole and old-growth longleaf pines to changes in the seeding rate are shown in Figure 53 and Figure 54 respectively.

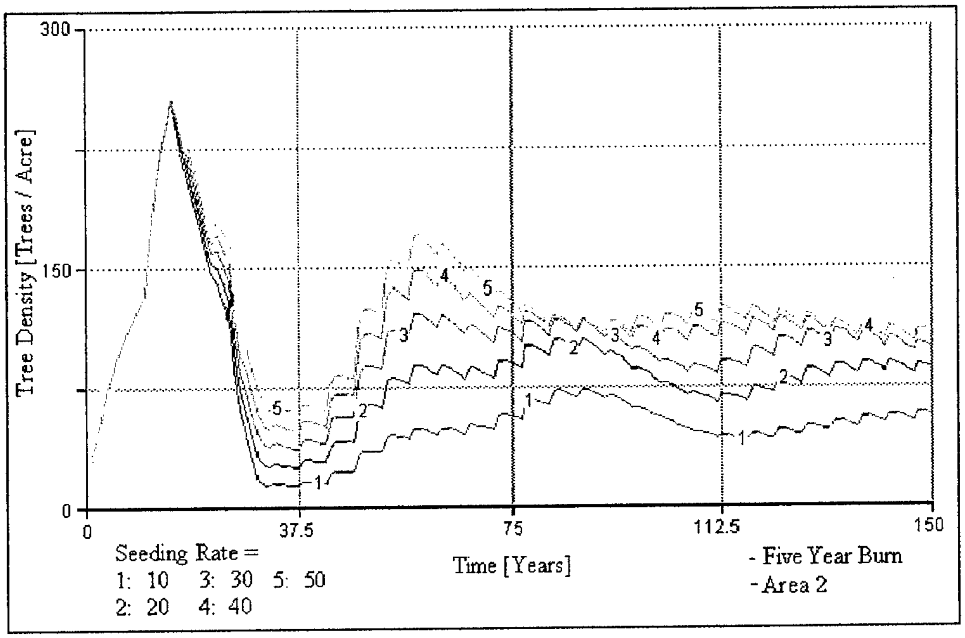

Figure 53: Effect of Seeding Rate on Small Pole Longleaf Pines

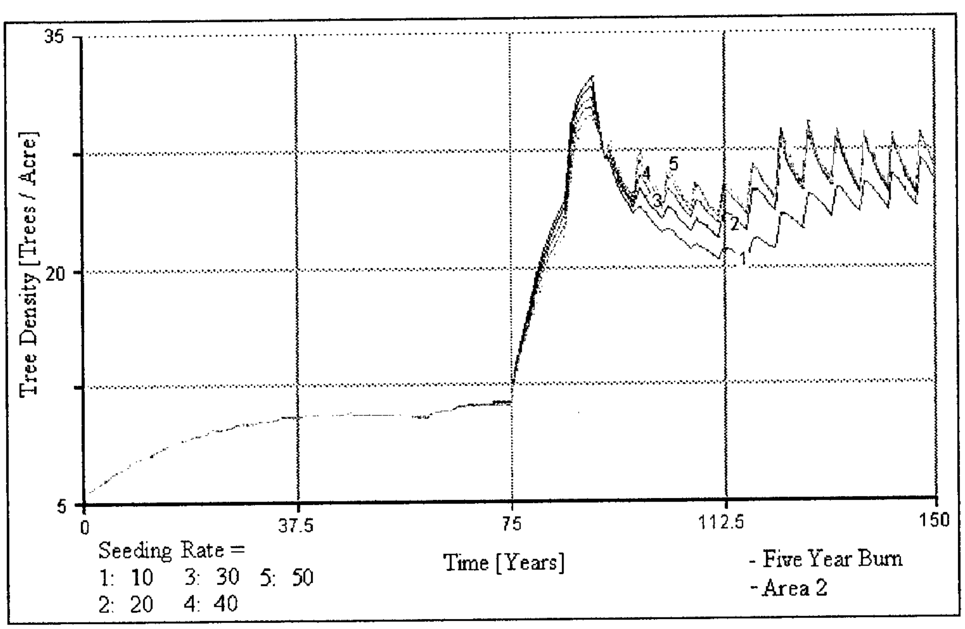

Figure 54: Effect of Seeding Rate on Old-Growth Longleaf Pines

Planted Longleaf Fire Protection. The "Fire Protection" provided to planted longleaf pines was ranged from 0.00 to 1.00. The model correlates 0.00 as no loss from fire (total protection from fire) and 1.00 equaling the regular mortality rate of 25%, (no fire protection). The fire frequency was held constant at a five-year prescribed burn interval. The results showed protecting planted longleaf pines from fire increases their density. Not all planted longleaf can be protected from fire loss, but a majority can be protected by using proper fire management. The model assumed protective management of planted longleaf from fires and sets the Fire Protection level at 0.20. The sensitivity of planted saplings to changes in the level of Fire Protection is shown in Figure 55.

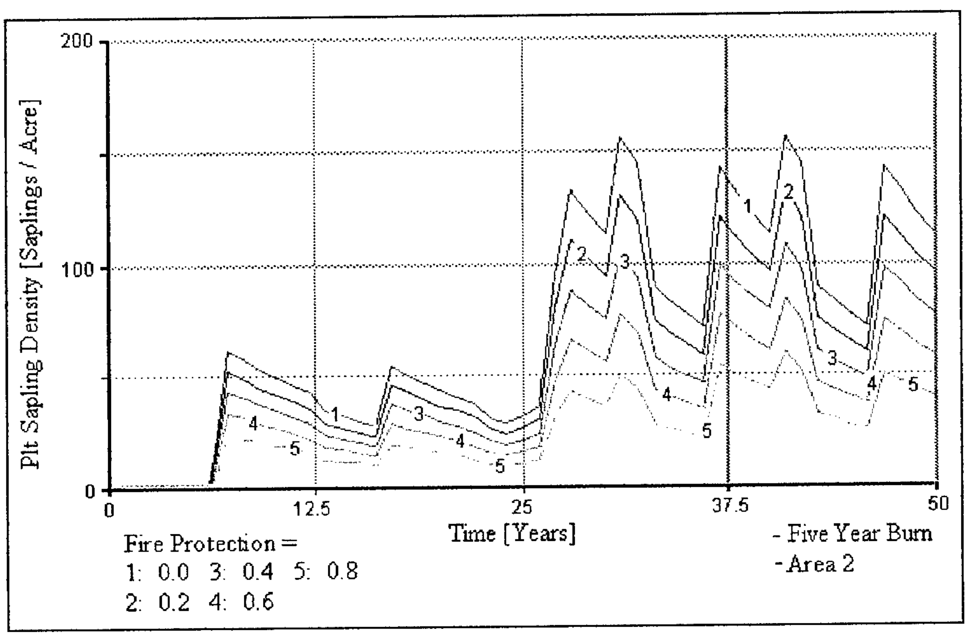

Figure 55: Effect of Fire Protection Levels on Planted Longleaf Pine Saplings

Hardwood Resprout Rate. The "Hardwood Resprout Rate" for pole hardwoods was ranged from 30% to 70%. The fire frequency was held constant at a five-year prescribed burn interval. The results showed that as the Resprout Rate increased, the hardwood density increased only slightly. The same results were shown when the fire frequency interval was lengthened. Therefore, the model set the Hardwood Resprout Rate at 50%, which is within the range of field studies on hardwood resprout rates.

SFS Birth Rate. The SFS annual birth rate was ranged from 0.5 to 2.5 offspring per adult SFS (or 1 to 5 offspring per adult female, assuming equal males and females in the population). The fire frequency was held constant at a five-year prescribed burn interval. The results showed that as the birth rate increased, so did both SFS age class populations. SFS birth rates in the wild are within the ranges tested. Therefore the model took the average and set the annual SFS birth rate at 1.5 offspring per adult SFS. The sensitivity of SFS adult population to changes in the SFS birth rate is shown in Figure 56.

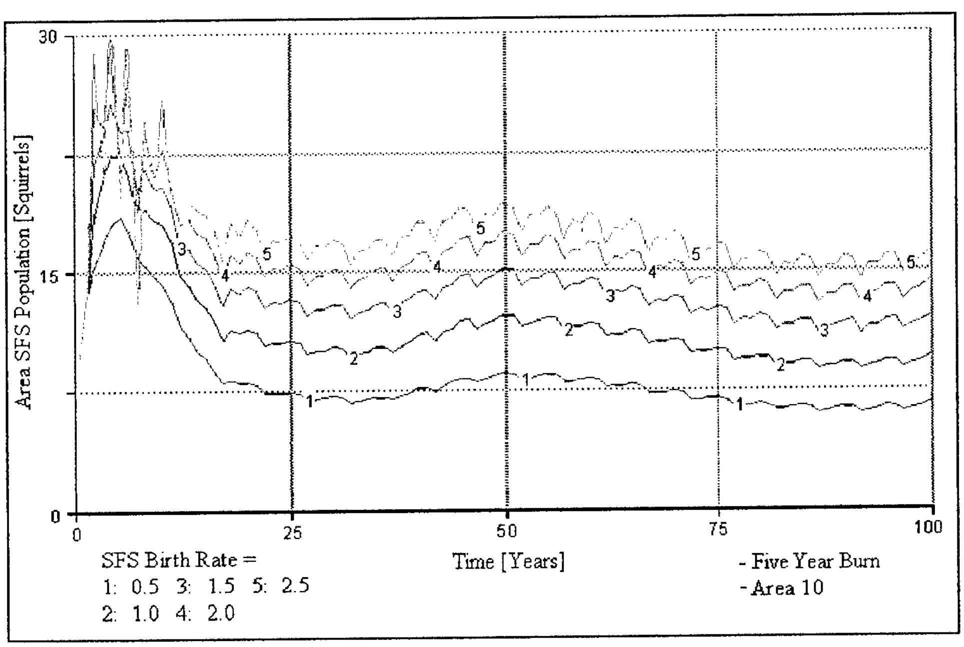

Figure 56: Effect of SFS Birth Rate on SFS Adult Population

Large Pole Foraging Rating. The "Large Pole Foraging Rating" for the pines was ranged from 0.6 to 1.0. The rating refers to the relative foraging quality of large pole age class trees when compared to mature and old-growth age class trees. Hence, at 0.25, the large pole age class trees were rated at 25% of the mature and old-growth age class trees' foraging quality. At 1.0, the large pole age class trees offered the same foraging quality as the mature and old-growth age class trees. The fire frequency was held constant at a five-year prescribed burn interval. The results showed that as the Large Pole Foraging Rating increased, so did the Foraging Index at a proportional rate. RCWs show preference towards the oldest trees to forage upon. Therefore, the Large Pole Foraging Rating for pines (age thirty to sixty years) should be comparably lower than the two oldest age classes. The Large Pole Foraging Rating for pines was set at 0.6. The Foraging Index sensitivity to changes in the Large Pole Foraging Rating is shown in Figure 57.

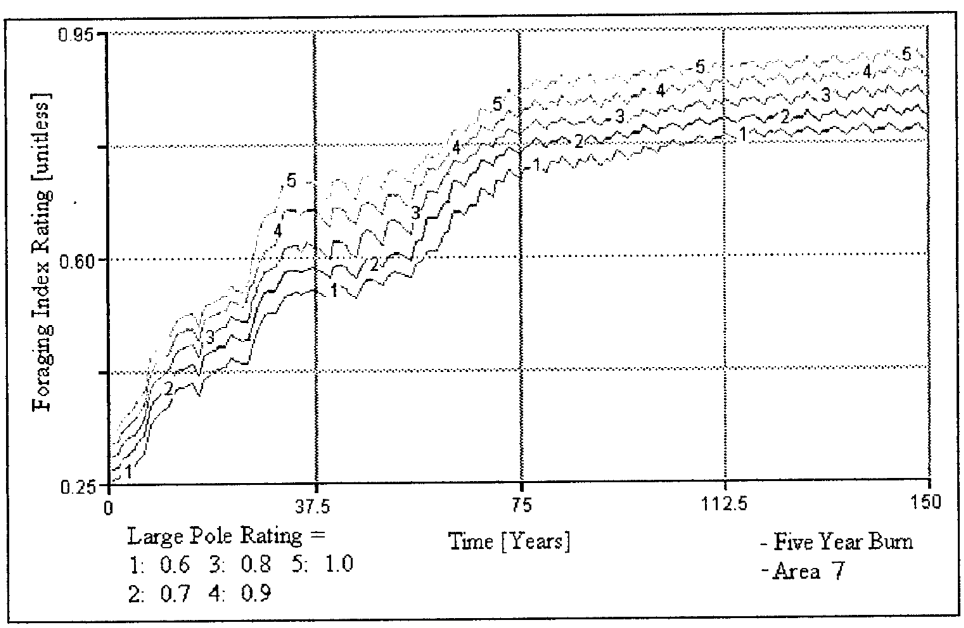

Figure 57: Effect of Large Pole Foraging Rating on Foraging Index

Slash Pine Foraging Rating. The "Slash Pine Foraging Rating" was ranged from 0.3 to 0.7. The Slash Pine Foraging Rating is similar to the Large Pole Foraging Rating. The Slash Pine Foraging Rating refers to the relative foraging quality of slash pines when compared to longleaf pines. Hence, at 0.5, the slash pine is rated at 50% of the longleaf pines' foraging quality. At 1.0, slash pines offer the same foraging quality as longleaf pines. The fire frequency was held constant at a five-year prescribed burn interval. The results showed that as the slash pine rating increased, so did the Foraging Index at a proportional rate. RCWs prefer to forage upon longleaf pines to slash pines. Therefore, the foraging rating for slash pines should be comparably lower than the longleaf pine. The Slash Pine Foraging Rating was set at 0.5. The sensitivity of the Foraging Index to changes in the Slash Pine Foraging Rating is shown in Figure 58.

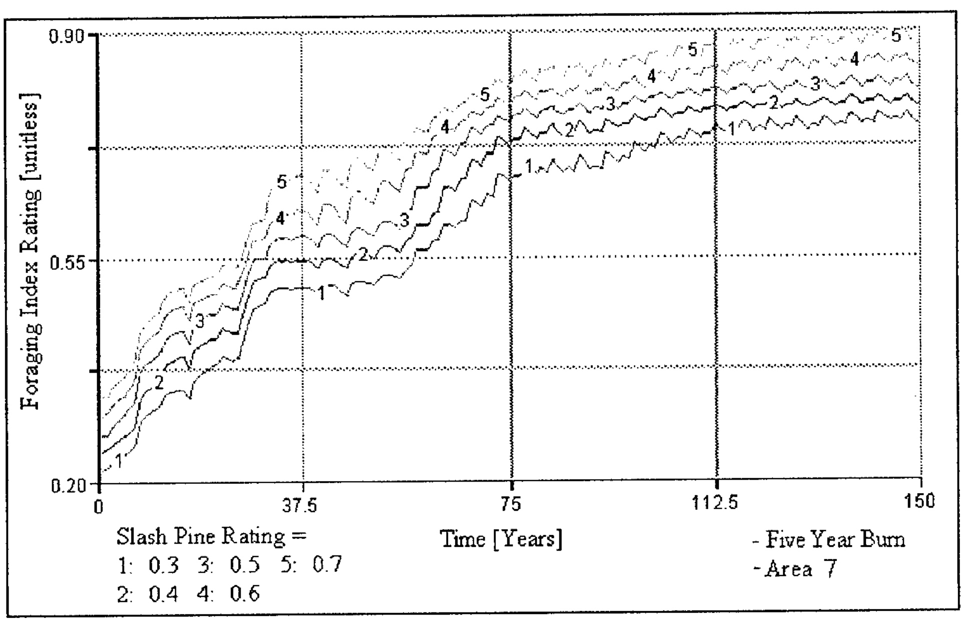

Figure 58: Effect of Slash Pine Foraging Rating on Foraging Index

Added Cavity Tree Mortality. The amount added to the mortality rate of cavity trees was ranged from 1% to 5%. The fire frequency was held constant at a five-year prescribed burn interval. The results showed that the cavity tree mortality had relatively little effect upon the dynamic steady-state RCW population. Studies have shown that annual cavity tree mortality ranges from 4% to 9%. The model's baseline annual mortality for trees of cavity age was around 2%. Therefore, assuming a rough average of cavity tree mortality, the added mortality of the cavity trees was set at 4% for a total cavity tree mortality rate of 6%.

Cavity-Enlarging Birds. The number of cavity-enlarging birds in an area of the model was ranged from 0 to 20 birds. The fire frequency was held constant at a five-year prescribed burn interval. The results showed that as the number of cavity enlarging birds increased, the RCW population level decreased slightly. The PWR contains different types of birds known to enlarge RCW cavities. Therefore, the number of cavity enlarging birds was assumed and set at 10 per area.

RCW Mortality Magnitude. The "RCW Mortality Rate Magnitude" was adjusted from 0.95 to 1.1. The magnitude refers to the increase or decrease of the RCW mortality. Hence, at 0.95, the RCW mortality rate was deceased to 95% of the RCW mortality rate curve's value. At 1.1, the RCW mortality rate was increased to 110% of the RCW mortality rate curve's value. The fire frequency was held constant at a five-year prescribed burn interval. The RCW population was quite susceptible to changes in the RCW Mortality Rate Magnitude. As the RCW Mortality Rate Magnitude increased, the RCW population level decreased. An optimistic RCW mortality magnitude was set at 1.00. Therefore, the model assumed the baseline RCW mortality rate. The sensitivity of the RCW population to changes in the RCW Mortality Rate Magnitude is shown in Figure 59.

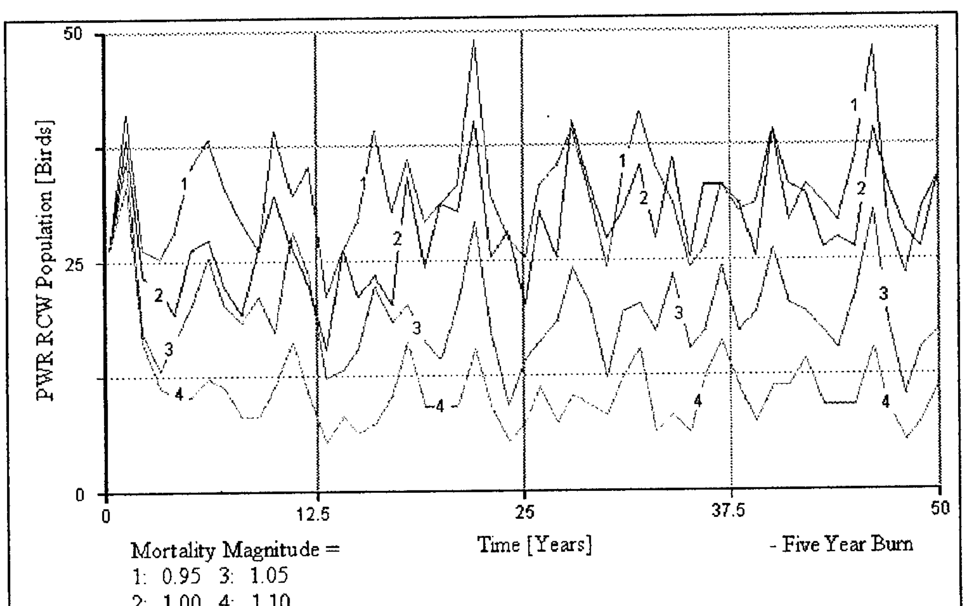

Figure 59: Effect of RCW Mortality Magnitude on RCW Population

RCW Female Mortality Increase. The RCW female mortality was increased from 100% to 130% of the RCW male's mortality rate. The fire frequency was held constant at a five-year prescribed burn interval. The RCW population was again susceptible to changes in the female RCW mortality rate. As the female mortality increased, the RCW population decreased. RCW mortality rates are typically 10% to 15% higher than RCW male mortality rates. Therefore, the RCW female mortality was set at 110%. The sensitivity of the RCW population to changes in the female RCW mortality increase is shown in Figure 60.

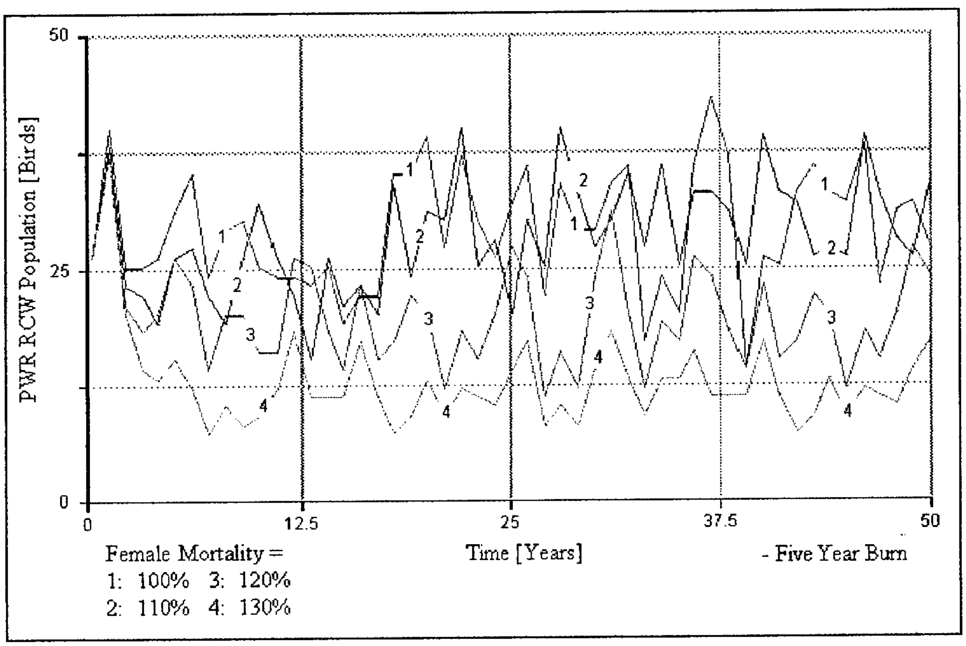

Figure 60: Effect of RCW Female Mortality Rate on RCW Population

RCW Male Presence Effect on Male Movement. The effect that RCW males have on the dispersion and immigration of other RCW males into a group was ranged from 0.6 to 1.0. An effect value of 0.6 means that the RCW male was dissuaded to immigrate into an area with a RCW group on account of another male RCW already in the group. Also, a 0.6 effect value means that a male RCW would not want to leave an area if it was the only male in the area. The magnitude of the effect lessens as the effect values gets larger. An effect level of 1.0 means that there was no effect on the decision of a male RCW to disperse away or immigrate into a group based on the presence of other RCW males. The fire frequency was held constant at a five-year prescribed burn interval. The RCW population decreased (just slightly sensitive) as the effect values increased. RCW males try not to immigrate into areas occupied by other male RCWs. However, RCW males are not totally dissuaded from immigrating into an area because of another RCW male. Therefore, the effect of a RCW male in an area on the immigration of another RCW male was set at 0.8.

RCW Male Presence Effect on Female Movement. The effect that RCW males have on the dispersion and immigration of female RCW into a group was ranged from 0.5 to 0.9. RCW females were dissuaded to immigrate into an area if there is not a male RCW present. Also, female RCW would want to leave an area if there was not a RCW male in the area. The effect value represented the effect magnitude. The magnitude of the effect lessened as the effect values got larger. The fire frequency was held constant at a five-year prescribed burn interval. The RCW population decreased as the effect value increased. Therefore, to reflect plausible RCW population behavior, the effect of a RCW male in an area on the immigration of a female RCW was set at 0.7. The sensitivity of the RCW population to changes in male effect on female dispersion and immigration is shown in Figure 61.

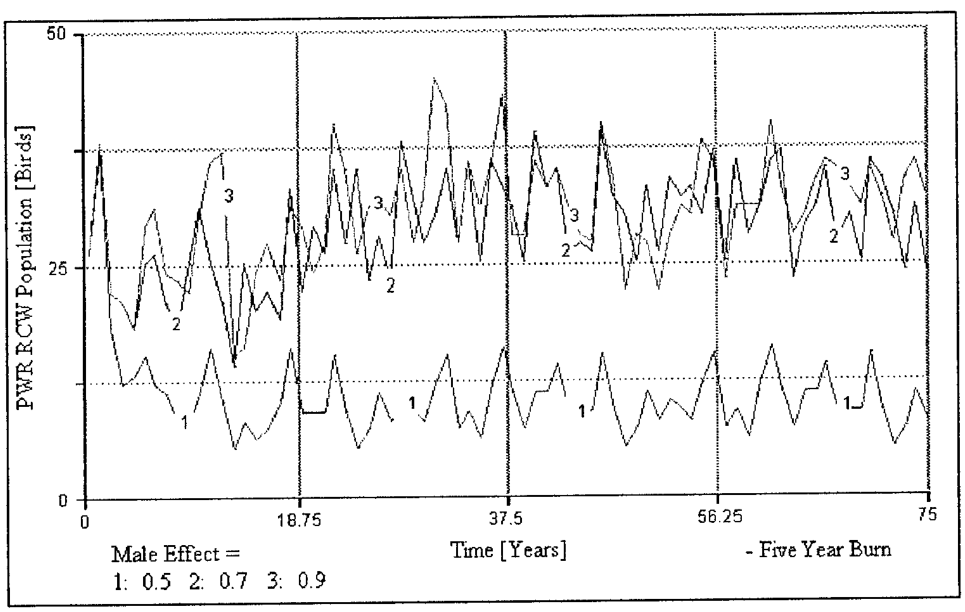

Figure 61: RCW Population Changes due to Effect of Males on Female Movement

RCW Dispersion Index Weights. Initially, the weights for the dispersion and immigration were intuitively set as: Foraging Index Dispersion = 2, Cavity Index Dispersion = 3, Corridor Index Dispersion = 1, Foraging Index Immigration = 1, and Cavity Index Immigration = 2. The weights were ranged from 1 to 5 in various combinations. Different weight combinations had all kinds of effects on the RCW population. Multiple iterations on the weight combinations were performed to represent the most plausible RCW population behavior. The final weights used were the following: Foraging Index Dispersion = 3, Cavity Index Dispersion = 4, Corridor Index Dispersion = 1, Foraging Index Immigration = 2, and Cavity Index Immigration = 5. The simulated RCW population that was conducted under a five-year burn interval and incorporated all the sensitivity test changes is shown in Figure 62. The population level hovered around 30 birds and the initial five groups remained intact.

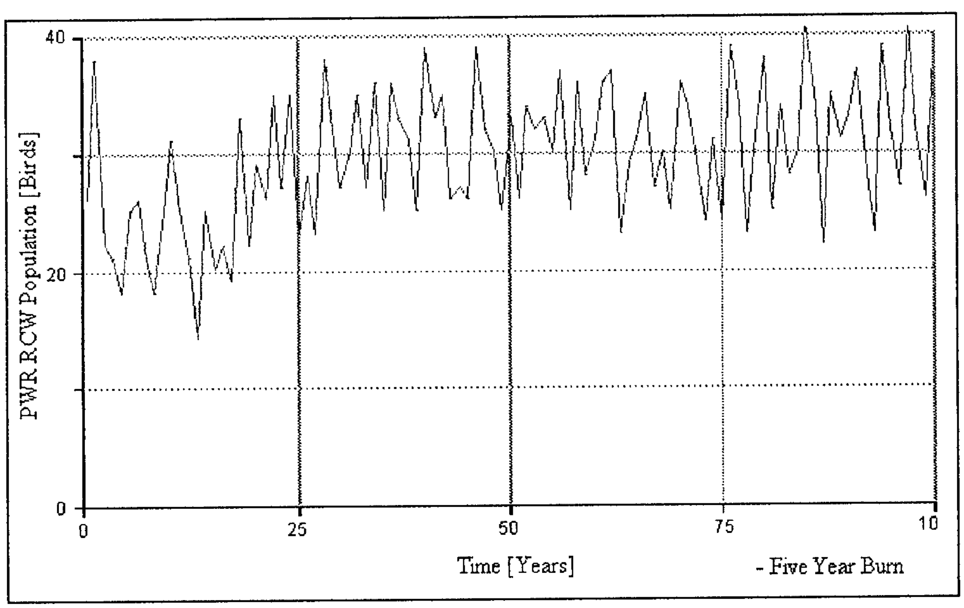

Figure 62: RCW Population after Sensitivity Calibration

Forest Management Scenario Simulations

Prescribed Burning. The burn interval was ranged from two to fourteen years between burns. Older pine age class growth all reached about the same dynamic steady-state levels. Fluctuations increased as the burn interval increased. The changes in the longleaf mature and old-growth age class densities from increased burn intervals are shown in Figure 63 and Figure 64, respectively. Time scales are truncated to show growth dynamics in the older age classes.

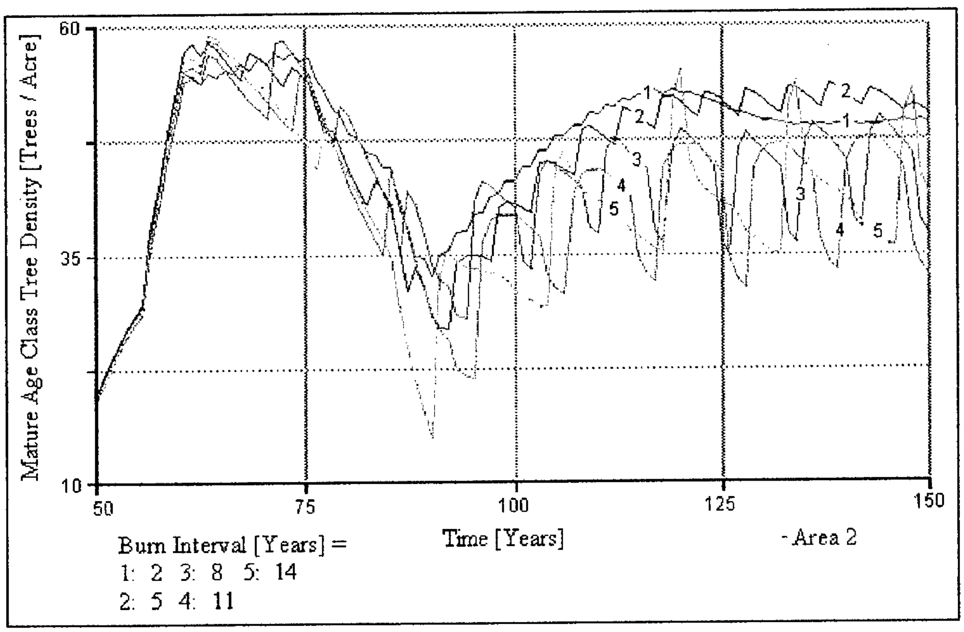

Figure 63: Effect of Prescribed Burn Interval on Mature Longleaf Pine

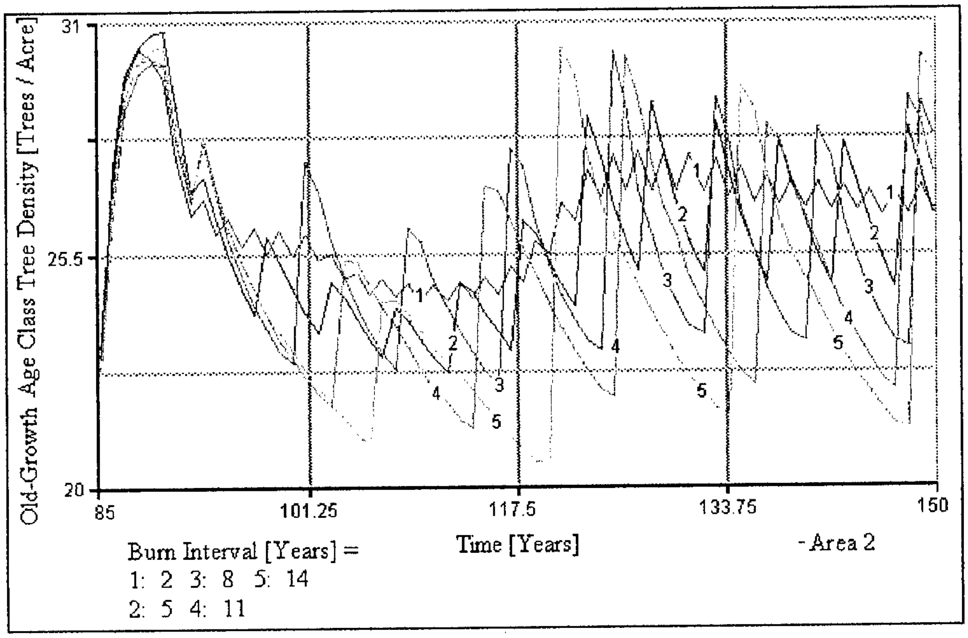

Figure 64: Effect of Prescribed Burn Interval on Old-Growth Longleaf Pine

The older slash pine age classes behaved similarly to longleaf pine. However, the slash pine was affected more negatively for the two-year burn interval. This reflected the slash pine's poor growth characteristics on the PWR.

The burn interval affected the hardwoods more than the pines. Burn intervals of two, five, and eight years were able to keep the hardwood pole size age class under control. The burn intervals of eleven and fourteen years allowed the hardwood density to peak back up right before the next burn. However, all the burn intervals were able to reduce the hardwood density. The changes in the hardwood pole age class density from increased burn intervals are shown in Figure 65. The spike in Trace 5 (fourteen year burn interval) at year twenty was from hardwood saplings, not killed in the first fire, developing into the pole age class. This spike only occurred in Trace 5 because the burn interval was long enough to allow for sapling maturation.

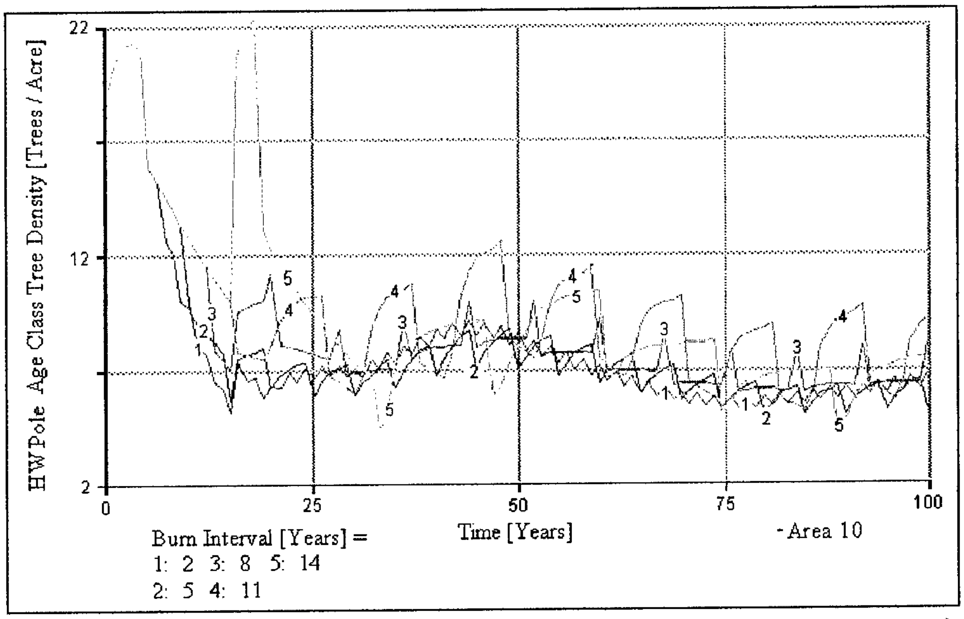

Figure 65: Effect of Prescribed Burn Interval on Pole Size Hardwood Density

Hardwood Thinning. Introducing hardwood thinning lowered the hardwood pole density, as would be expected. However, thinning alone could not keep the hardwood density down because thinning did not clear out hardwood saplings. Using thinnings in conjunction with burning lowered the hardwood density more than with just burning alone. The effect on the density of pole hardwoods using thinnings is shown in Figure 66 and Figure 67 for both a five-year and eleven-year burn interval respectively. Thinnings were conducted on a ten-year harvest interval. The amount of hardwoods thinned was set at 75%. Trace 1 refers to just a ten-year harvest rate, Trace 2 refers to just the burn interval specified, and Trace 3 refers to both burning and thinning.

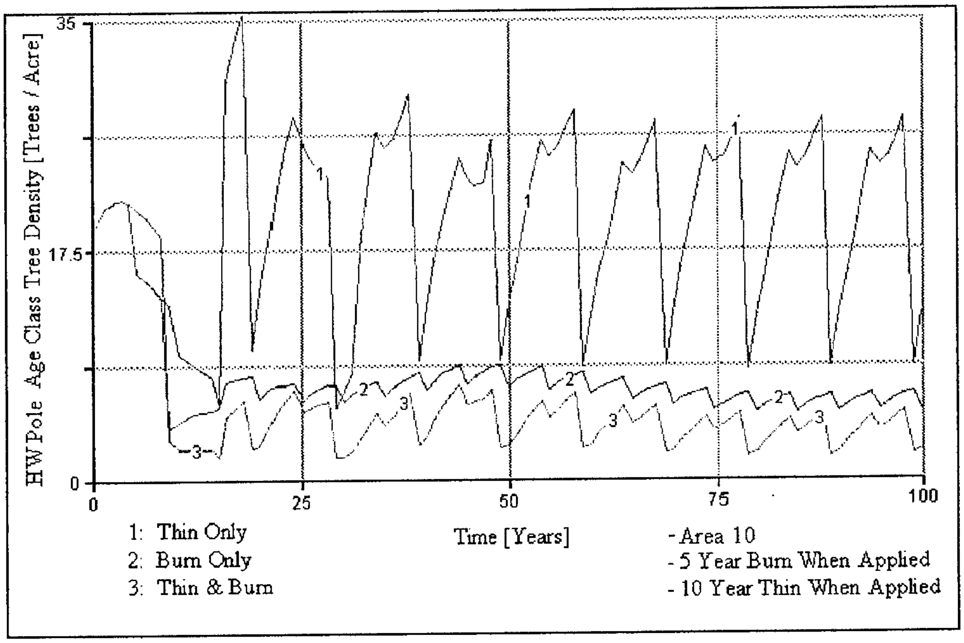

Figure 66: Effect of a Five-Year Burn Interval and Thinnings on Pole Size Hardwoods

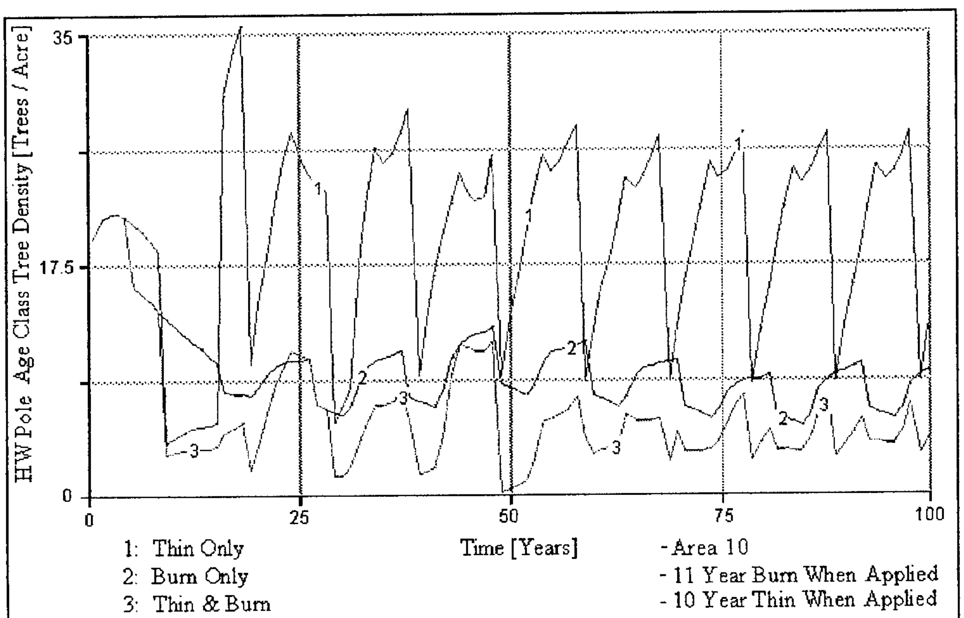

Figure 67: Effect of a Eleven-Year Burn Interval and Thinnings on Pole Size Hardwoods

Pine Thinning. Pine thinning at long intervals and low timber amounts allowed the older pine age classes to reach the same level as without thinning. When thinning intervals and harvest amounts increased, the steady-state levels of the pine age classes' decreased. The effect of thinning old-growth longleaf pines is shown in Figure 68 for a five-year burn interval. Thinnings were conducted on a twenty-five-year harvest level. The amount of small pole and large pole longleaf pines thinned was set at 20%.

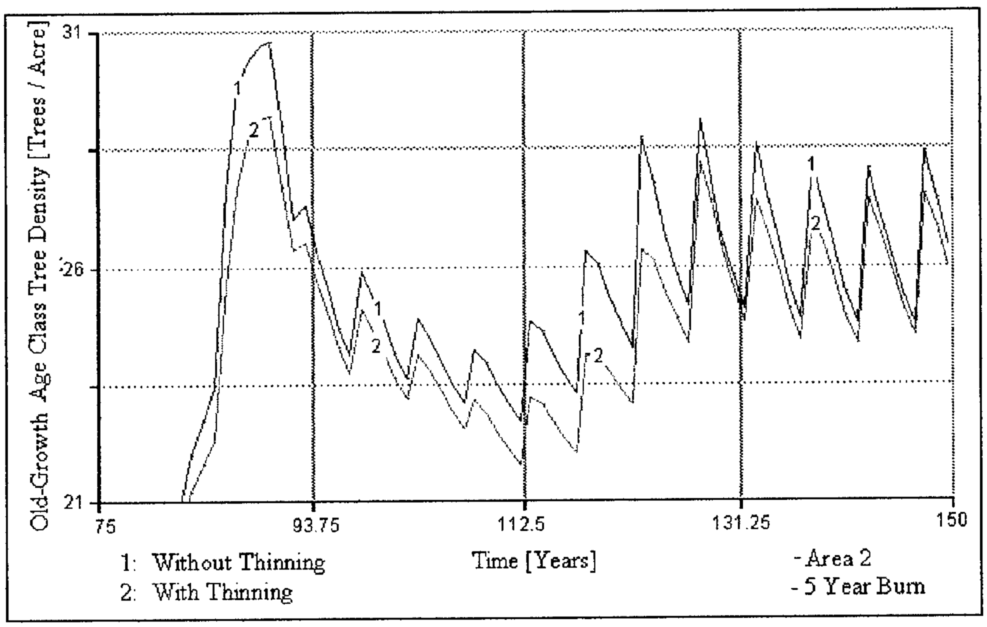

Figure 68: Effect of Burning with and w/o Thinnings on Old-Growth Longleaf Pines

Herbicide Application. Using herbicides lowered the hardwood pole density. Similar to just using hardwood thinning, herbicides alone could not keep the hardwood density down because herbicides were not applied to hardwood saplings. Applying herbicides in conjunction with burning lowered the hardwood density more than with just burning alone. The effect on the density of pole hardwoods using herbicides is shown in Figure 69 and Figure 70 for both five-year and eleven-year burn intervals, respectively.

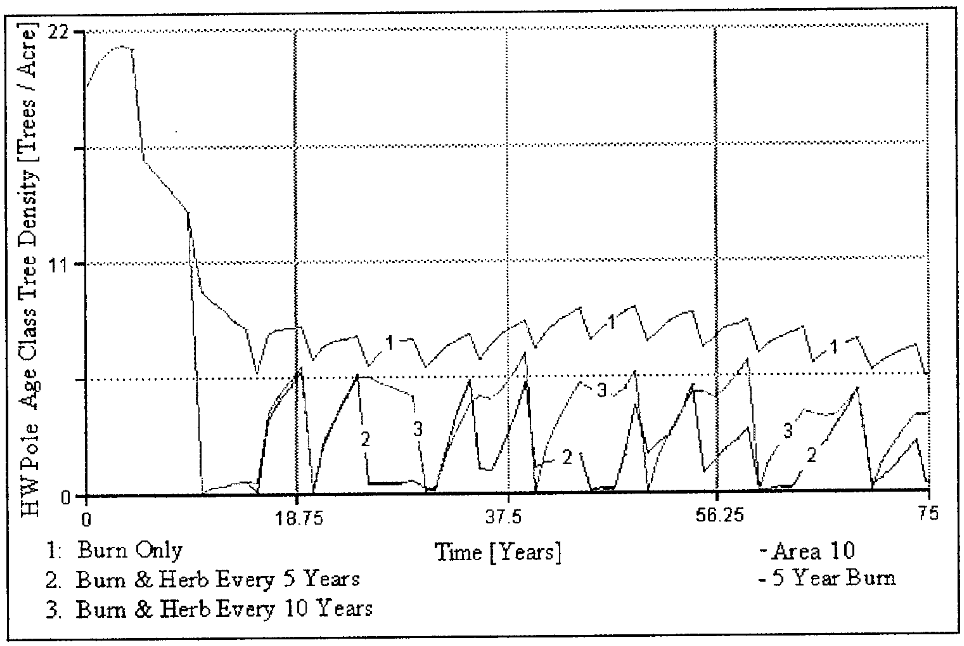

Figure 69: Effect of Five-Year Burns w/ Herbicide Use on Pole Size Hardwood Density

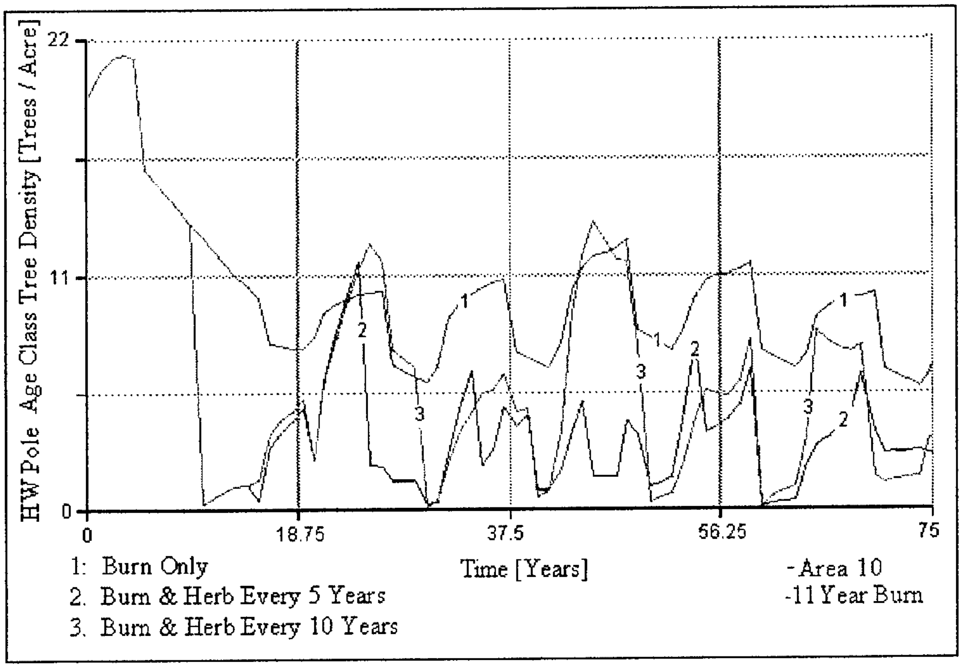

Figure 70: Effect of Eleven-Year Burns w/ Herbicide Use on Pole Size Hardwood Density

Proposed Forestry Management Alternatives

Five alternatives of forest management (FM) combinations were compiled that represent different management strategies. The strategies offer the PWR ecosystem managers different possibilities in the allocation of management resources. All of the alternatives arrived at similar dynamic steady-state RCW population levels. A description of each alternative is listed below.

FM Alternative 1. The first FM alternative applied just a five-year prescribed burning interval. A five-year burn interval is the recommended interval to replicate the fire frequency of the original southern pine forests. Five-year burns provide necessary hardwood control and optimal pine regeneration conditions. The five-year prescribed burn interval was the baseline management practice for the model's development.

FM Alternative 2. The second FM alternative applied just a ten-year prescribed burning interval. A ten-year burn interval still provides the needed fire effects for the forest. However, the ten-year gap allows greater hardwood encroachment and less seed germination potential. This alternative required the least amount of resources.

FM Alternative 3. The third FM alternative applied a ten-year prescribed burn interval and hardwood clearing every ten years. This alternative provided alternating techniques for hardwood control. Consequently, the hardwood harvesting required additional use of resources.

FM Alternative 4. The forth FM alternative applied a ten-year prescribed burn interval and an application of herbicide every ten years. Similar to FM Alternative 3, FM Alternative 4 provided variable means for hardwood control. Likewise, FM Alternative 4 required additional expenditure of resources.

FM Alternative 5. The fifth FM alternative applied a five-year prescribed burn interval and a periodic pine thinning. The pine thinning is done every twenty-five years at 20% cut rates of the pine trees in the small pole and large pole age classes. Thinning at this rate and amount did not adversely affect the older pine age class densities while in turn providing additional timber revenue. Harvests were conducted only in areas that were capable of being thinned.

RCW Management Scenario Simulations

Cavity Restrictor Plates. The test range of restrictor plate installment varied from one to five restrictors installed per area at installment intervals from five to twenty years. Restrictor plates were only installed to degraded cavities. The installment of restrictor plates did not show significant increases in the RCW population level. All of the FM

alternatives displayed the same results. Although the model shows only minor RCW population increases from cavity plate installment, RCWs will use cavities installed with restrictor plates. The model does not delineate occupied RCW cavities with restrictor plates installed from occupied cavities without restrictor plates.

Artificial Cavities. The test range of artificial cavity installment, either with a cavity insert box or by drilling, varied from one to three restrictors installed per area at installment intervals of ten, fifteen, and twenty years. No more than three artificial cavities per area were installed for two reasons. One, artificial cavity installation requires the expenditure of a lot of resources. Two, providing a majority of the RCW cavities could allow the RCWs to rely totally on artificial cavities instead of constructing cavities themselves. When the artificial cavity installed amount was one cavity, the RCW population increase was very small for all three installment intervals. No new groups formed probably because RCW group creation needs at least two cavities. Group formation occurred when the installment amount was two cavities and the installment rate was either ten or fifteen years. When the installment amount was three cavities, approximately three to four new groups formed and the RCW population increased to roughly 55 birds for all three installment intervals. All of the FM alternatives displayed relatively the same results. The effect of artificial cavity installment on the RCW population is shown in Figure 71 for FM Alternative 1. Installments were conducted on a fifteen-year interval.

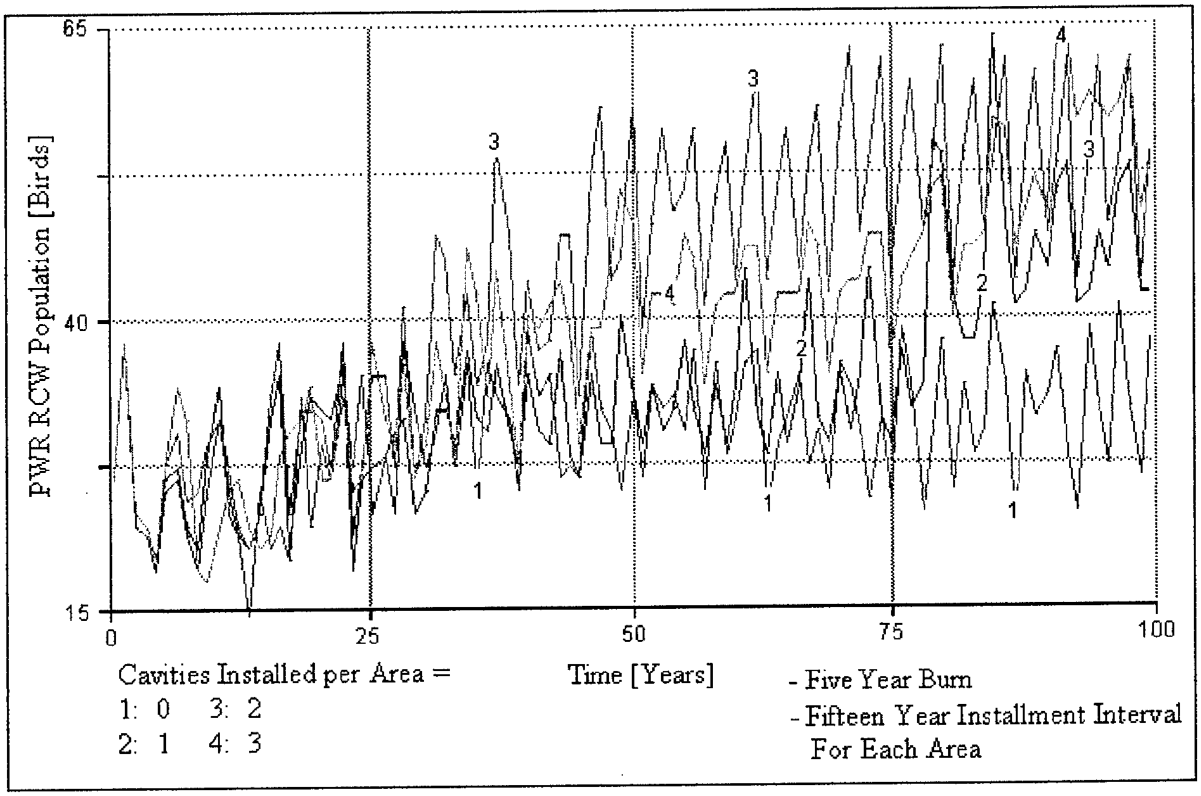

Figure 71: Effect of Artificial Cavity Installment on RCW Population

<u>SFS Removal</u>. SFS annual removal rates were set at 25%, 50%, and 75%. SFS capture rates of 50% or higher significantly increased the RCW population. All of the FM alternatives displayed relatively the same results. The effect of SFS capture on the RCW population is shown in Figure 72 for FM Alternative 1.

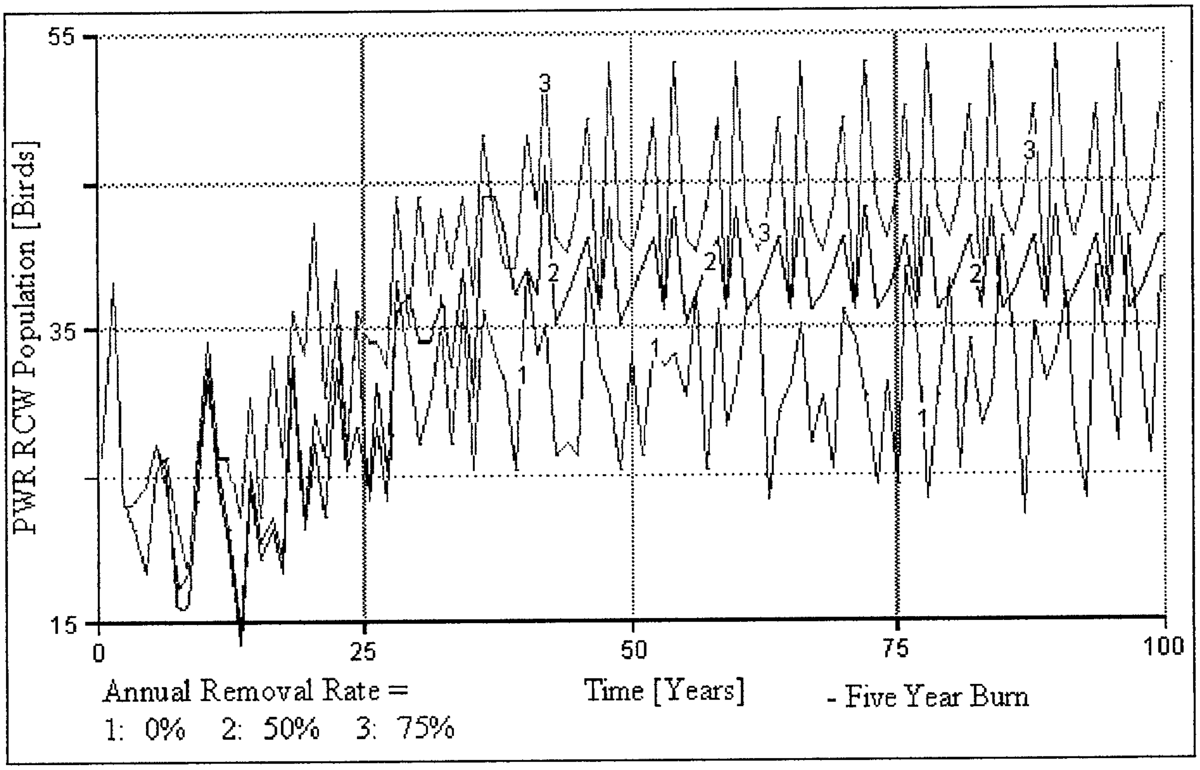

Figure 72: Effect of SFS Removal on RCW Population

RCW Management Combination. Cavity plate restrictors were installed in amounts of five per area at ten-year intervals. Artificial cavities were installed in amounts of two per area at ten-year intervals. The SFS annual capture rate was set at 50%. The result showed a huge increase in the RCW population. Eventually, RCW groups occupied all of the areas in the PWR. This extensive management combination used with FM Alternative 1 brought the RCW population to roughly 90 birds. The results are shown in Figure 73.

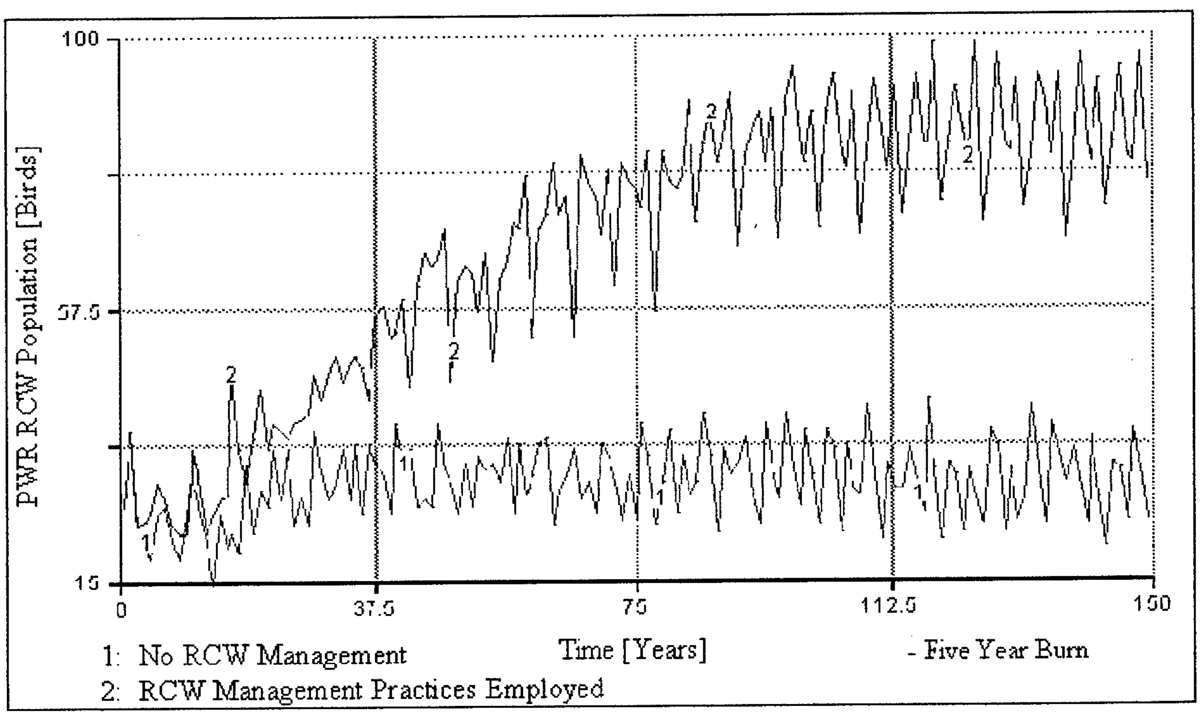

Figure 73: Effect of Extensive RCW Management on RCW Population

RCW Translocation. Male and female RCW of the same age were paired up and released together in areas without RCW groups. Translocation pairs were either one or two years old. Translocations were preformed in various combinations. The results showed that RCW groups were created most of the time if the translocated RCW pair was released into an area with cavities and adequate foraging habitat. If areas were devoid of cavities, the released RCWs would either die or try to immigrate into new areas. The age of the translocated pair made a difference in the pair's survival in a couple of instances. The translocation of a one-year old RCW pair into Area 14 is shown in Figure 74. This translocation was performed at the 25-year point using FM Alternative 1. Area 14 does not initially contain cavities. A RCW group was created only when artificial cavities were installed in the area in conjunction with the translocation.

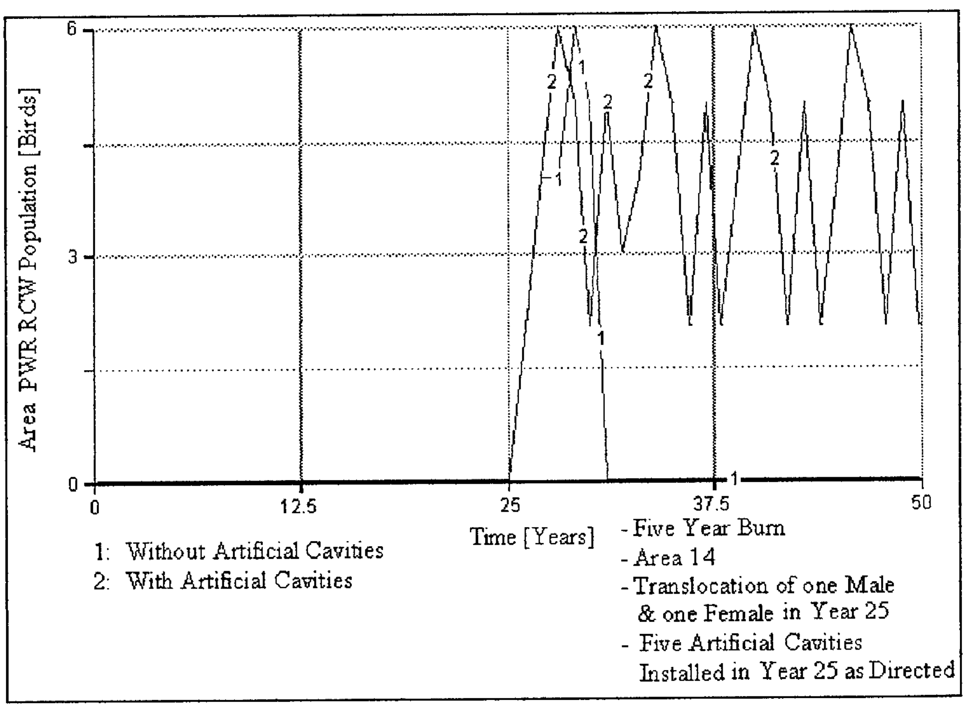

Figure 74: Effect of Installment of Artificial Cavities on RCW Translocation

Proposed RCW Management Alternatives

The five FM alternatives were each used during the simulation testing of the RCW management techniques. All five alternatives showed relatively the same output for every simulation run for the different RCW management techniques. Therefore, the five FM alternatives can be used interchangeably when applying RCW management techniques. This allows the PWR ecosystem managers to use the FM alternative that best suits the needs of forest at any particular time.

Six alternatives of RCW management (RM) combinations were compiled that represent different types of RM strategies. As with the FM alternatives, the varying strategies offer the PWR ecosystem managers different possibilities in the allocation of management resources. A description of each alternative is listed below. The resultant PRW RCW populations from each RM alternative are shown in Figure 75.

RM Alternative 1. The first RM alternative installed cavity plate restrictors in amounts of five per area at ten-year intervals. This alternative required the resources needed to install and maintain the restrictor plates.

RM Alternative 2. The second RM alternative installed artificial cavities in amounts of two per area at ten-year intervals. This alternative required the resources needed to install and maintain the artificial cavities.

RM Alternative 3. The third RM alternative captured and removed approximately 50% of the SFS in the PWR annually. This alternative required the resources needed to install squirrel boxes and remove the SFS from the boxes.

RM Alternative 4. The forth RM alternative combined the first three RM alternatives. The description of RM Alternative 4 was previously explained (refer to Figure 73). This alternative required the most resources of all the RM alternatives.

RM Alternative 5. The fifth RM alternative translocated pairs of RCWs into areas in the PWR without RCW groups. A translocation of a two-year old pair occurred every five years. The RCW pairs were released in a rotation every five years between Area 3, 10, and 14, which were initially devoid of a RCW group. Translocations were accompanied with the installment of artificial cavities. This alternative required artificial cavity installment resources and the specific resources for RCW translocation.

RM Alternative 6. The sixth RM alternative is the null alternative, which did not apply any RM techniques. RM Alternative 6 was the same as FM Alternative 1, which applied only a five-year prescribed burn. RM Alternative 6 required the least amount of resources.

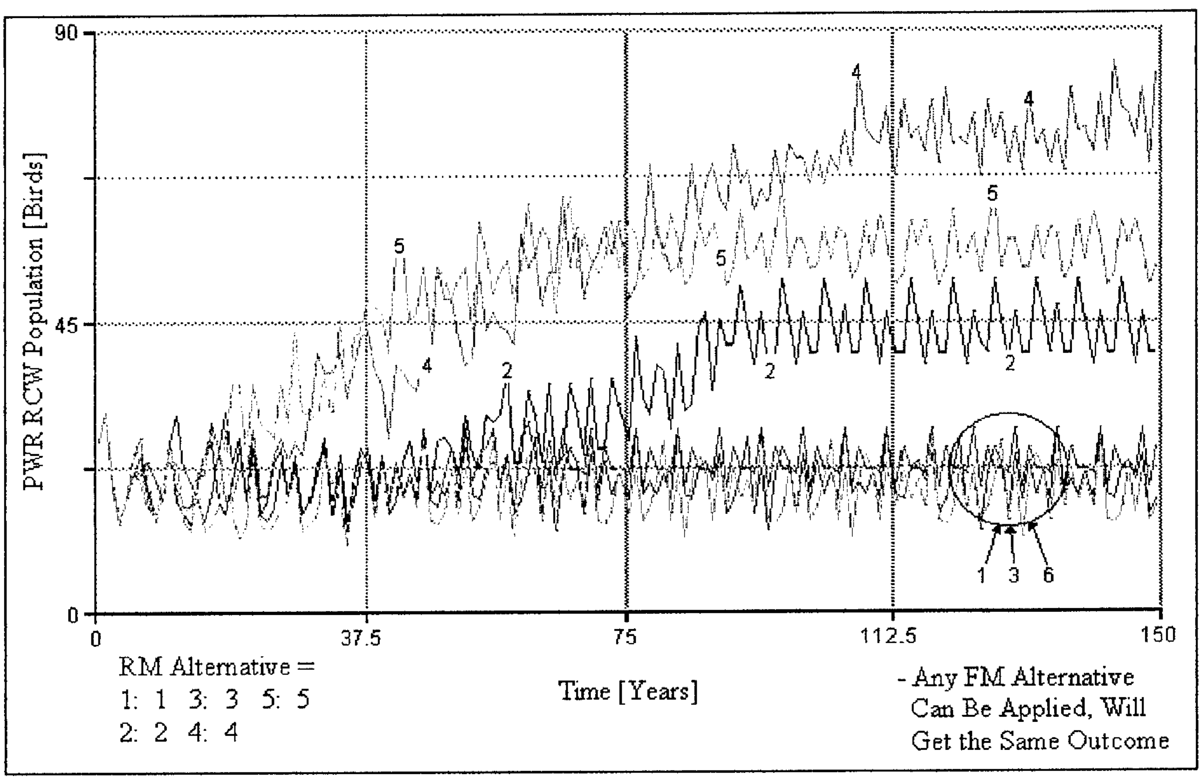

Figure 75: Effect of RM Alternatives on the RCW Population

Slash to Longleaf Pine Conversion

After simulating a few conversion runs, the Fragment Index, which made up part of the Foraging Index, needed recalibration. Initially, extreme conversion amounts simulated did not negatively affect the RCW population. This was not a plausible outcome because large patches of clear-cut areas in and around RCW habitat negatively affect the birds. This has been shown in many field studies that correlate habitat fragmentation to RCW cluster abandonment. There exists a minimum foraging habitat level, that when dropped below, negatively affects the RCW (Beckett, 1974:7; Beyer et al., 1996:834). The exact level varies depending on the circumstances of each RCW location, but the model needed to represent the mechanisms that negatively affected the RCW population due to habitat fragmentation. Thus, iteration of the system dynamics' steps was performed. Upon proper alignment of the Fragment Index curve and adjustment of the Fragment Index curve weight, the model displayed reasonable RCW population output for respective conversion settings. These changes gave fragmentation effects a greater impact in the Foraging Index. Due to the changes, the baseline RCW steady-state population level dropped from 30 to 20 birds. The population levels also dropped for all of the RM alternatives by about ten birds each. The modification actually improved the model by reflecting recent trends of the RCW population on the PWR.

After appropriate changes were made, the testing of conversion began. Areas that underwent conversion from slash pine to longleaf pine varied from 5 to 40 acres at a time for an area. The conversion frequency for an area ranged from five to fifteen years. A rotating conversion schedule was set that had four geographically separated areas beginning conversion of new tree stands every two years. Therefore, in ten years, each

area on the PWR had conversion underway. The reason for the rotating conversion schedule was to minimize the annual aggregate effect of conversion fragmentation on the PWR RCW population. The different conversion plans were simulated with each of the RM alternatives. RCW population behavior from the different management combinations are summarized in Table 1, which lists the conversion setting simulated, transitional RCW population growth behavior, relative impact of conversion on the RCW population compared to no conversion, and final dynamic steady-state RCW population level. Also shown in Table 1 is the number of years it takes to completely convert the entire PWR forest to longleaf pine.

In general, as the conversion acreage amount increased and/or the frequency of conversion decreased, the RCW population decreased. If the conversion frequency and amount was too much, the RCW population would collapse. An example of simulations used to compile the data for Table 1 is shown in Figure 76 for the RM Alternative 2, which used a ten-year conversion interval for each area. Trace 1 represents a conversion amount of 15 acres, which resulted in a continually growing RCW population. The population growth occurred when converted longleaf pines reached foraging age and later on when the converted longleaf pines reached nesting age. Trace 2 represents a conversion amount of 20 acres, which resulted in an initial RCW population decrease followed by an increase. The initial decrease was a result of the negative fragmentation effects on the RCW because of the amount of acreage undergoing conversion. Later, the RCW population recovered and increased upon the maturation of the converted longleaf pine. Trace 3 represents a conversion amount of 25 acres, which resulted in a RCW

population crash. This result was due to the RCW population not being able to overcome the fragmentation effects of the converted acreage amount.

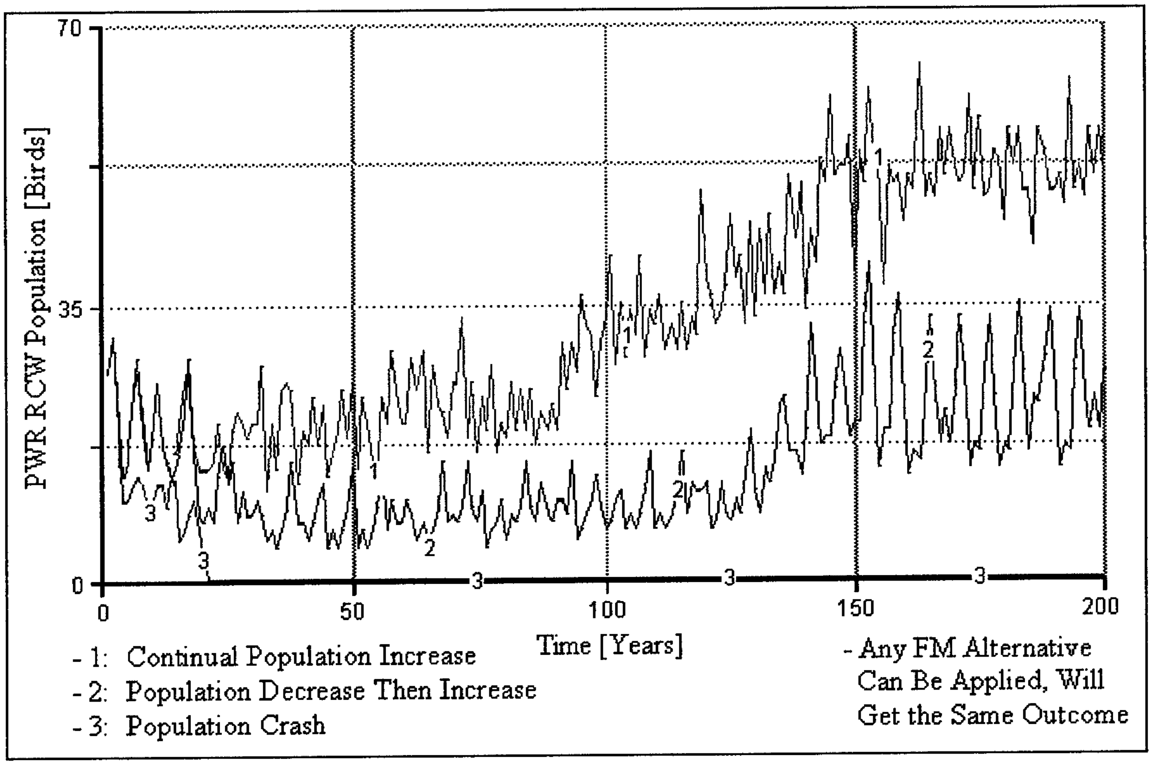

Figure 76: Effect of Different Conversion Amounts on the RCW Population

Table 1: RCW Population Levels After Different Conversion Settings

Conversion																										
Frequency per Area [years]		0	5	5	5	5	5	5	5	5	10	10	10	10	10	10	10	10	15	15	15	15	15	15	15	15
Amount per Area [acreage]		0	5	10	15	20	25	30	35	40	5	10	15	20	25	30	35	40	5	10	15	20	25	30	35	40
Total for PWR [acreage]		0	20	40	60	80	100	120	140	160	20	40	60	80	100	120	140	160	20	40	60	80	100	120	140	160
RCW Management Alternatives	Behavior		+	- +	- +	- -	- -	- -	- -	- -	+	+	+	- -	- -	- -	- -	- -	+	+	+	-	- -	- -	- -	- -
1	Result		PI	PI	PI	CR	CR	CR	CR	CR	PI	PI	PI	CR	CR	CR	CR	CR	PI	PI	PI	PD	CR	CR	CR	CR
	SS Pop	20	30	25	30	0	0	0	0	0	35	30	30	0	0	0	0	0	25	30	35	10	0	0	0	0
	Behavior		+	- -	- -	- -	- -	- -	- -	- -	+	+	+	- +	- -	- -	- -	- -	+	+	+	+	-	-	- -	- -
2	Result		PI	CR	CR	CR	CR	CR	CR	CR	PI	PI	PI	PI	CR	CR	CR	CR	PI	PI	PI	PI	PD	PD	CR	CR
	SS Pop	45	50	0	0	0	0	0	0	0	55	55	50	30	0	0	0	0	55	55	50	50	10	10	0	0
	Behavior		+	- +	-	- -	- -	- -	- -	- -	+	- +	-	- -	- -	- -	- -	- -	+	+	- +	- +	-	- -	- -	- -
3	Result		PI	PD	PD	CR	CR	CR	CR	CR	PI	PI	PD	CR	CR	CR	CR	CR	NC	PI	PI	PD	PD	CR	CR	CR
	SS Pop	25	40	20	15	0	0	0	0	0	40	45	10	0	0	0	0	0	25	35	45	20	10	0	0	0
	Behavior		+	- +	- -	- -	- -	- -	- -	- -	+	+	+	- +	- -	- -	- -	- -	+	+	+	+	- +	- +	- -	- -
4	Result		PI	PD	CR	CR	CR	CR	CR	CR	PI	PI	PI	PI	CR	CR	CR	CR	PI	PI	PI	PI	PD	PD	CR	CR
	SS Pop	75	85	60	0	0	0	0	0	0	80	85	85	80	0	0	0	0	85	85	85	85	70	70	0	0
	Behavior		+	- +	- -	- -	- -	- -	- -	- -	+	+	+	- +	- -	- -	- -	- -	+	+	+	+	- +	- +	- -	- -
5	Result		NC	PD	CR	CR	CR	CR	CR	CR	NC	NC	NC	NC	CR	CR	CR	CR	NC	NC	NC	PD	PD	PD	CR	CR
	SS Pop	55	55	45	0	0	0	0	0	0	55	55	55	55	0	0	0	0	55	55	55	50	50	50	0	0
	Behavior		+	-	-	- -	- -	- -	- -	- -	+	- +	-	- -	- -	- -	- -	- -	+	+	+	-	-	- -	- -	- -
6	Result		PI	PD	PD	CR	CR	CR	CR	CR	PI	PI	PD	CR	CR	CR	CR	CR	NC	PI	PI	PD	PD	CR	CR	CR
	SS Pop	20	30	10	10	0	0	0	0	0	30	30	10	0	0	0	0	0	20	30	35	10	10	0	0	0
Years to Full Conversion			275	150	110	100	90	80	70	65	500	260	185	150	125	105	95	90	700	375	270	200	175	140	120	100

Legend

Transitional behavior		Result compared to no conversion	
+	: Population continually grew	PI	: Population increased
- +	: Population declined and then grew	NC	: No change in population
-	: Population declined	PD	: Population decreased
- -	: Population crashed	CR	: Population crashed

Slash Pine Foraging Rating

The Slash Pine Foraging Rating was tested again after final model calibration. The second test was run because of the relevance of the slash pine's impact on the foraging rating. The initial sensitivity test set the Slash Pine Foraging Rating at 0.5 (refer to Figure 57). The rating indicated that a slash pine's value in the Foraging Index was only 50% of the longleaf pine's value in the Foraging Index. The second sensitivity test ranged the Slash Pine Foraging Rating from 0.0 to 1.0 under FM Alternative 6 with no conversion. Increasing the Slash Pine Foraging Rating only slightly increased the RCW population. A 0.0 rating meant that the slash pine had no impact on the Foraging Index. A 1.0 rating meant the slash pine's foraging quality equaled the longleaf pine's foraging quality. Similar results were display using different management alternatives. The sensitivity of the RCW population to changes in the Slash Pine Foraging Rating under FM Alternative 6 with no conversion is shown in Figure 77.

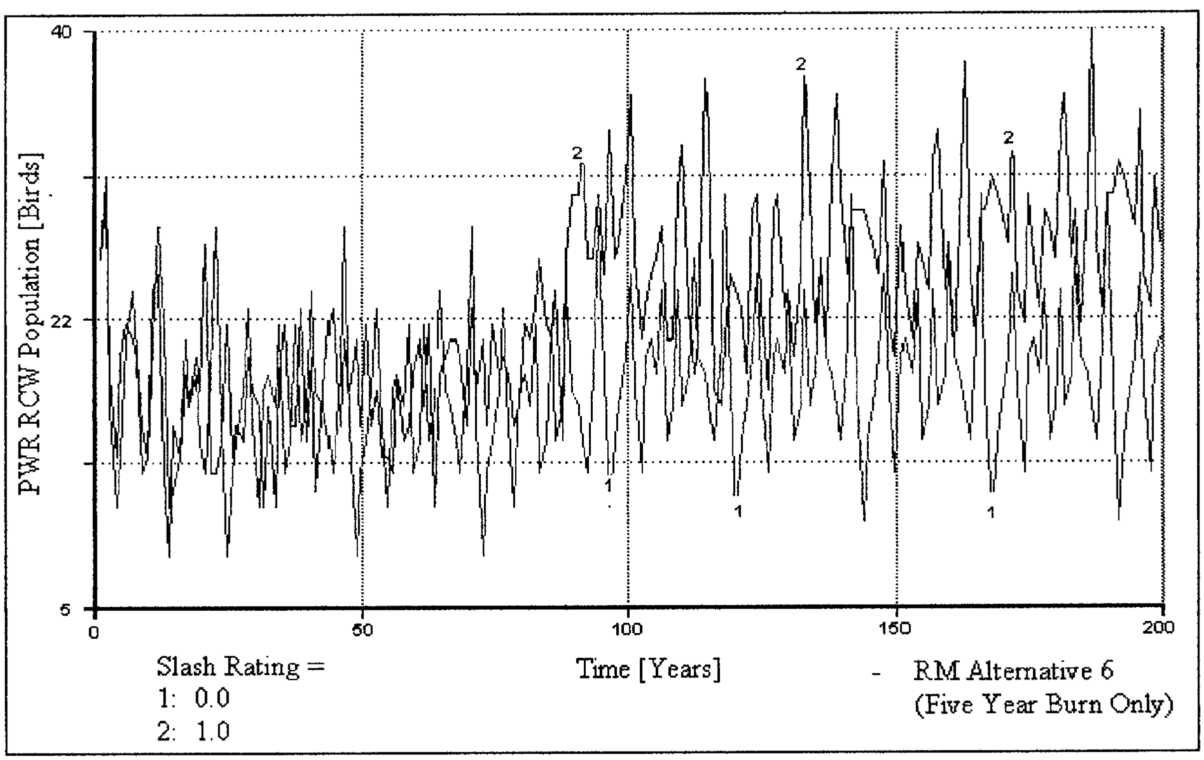

Figure 77: Effects of the Slash Pine Foraging Rating on the RCW Population

Model Limitations

Despite the complexity, there were many assumptions and accepted limitations made during development and construction of the model. Assumptions were highlighted in Chapter 3's explanations and descriptions of model variables. General assumptions and limitations of the model are outlined next. Models cannot exactly represent reality. Assumptions and limitations are inevitable.

Ecosystem Assumptions. The model design was extremely detailed to represent the complex behavior of the RCW. Nonetheless, the model was not able to incorporate every distinctive dynamic behavior of the RCW. Budding and pioneering (natural creation of clusters by RCWs) was not included in the model logic. The reasoning behind this was that the budding and pioneering rates, even for large RCW populations, are very small with an annual probability of 1% that an existing group will produce a new bud (Crowder, et al., 1998:3). For group formation to occur, the RCWs in the model had to rely on finding areas with vacated cavities or areas that were artificially augmented with cavities. However, if unoccupied for a long time in the model, the vacant cavities eventually degraded. This in turn rendered the area unsuitable to the RCWs. Other logic not included was the complete avoidance of incestuous behavior. The model did force young female RCWs to leave their natal group. Also, dispersing females would not immigrate into groups already occupied by a breeding female. However, the model did not account for the dispersal of a female from a group when one of her sons assumed the breeding role due to his father's death. Another important biological inference not incorporated by the model was the loss of heterozygosity due to genetic drift. This is

especially prevalent in small isolated RCW populations, like the one on the PWR. Model exclusion of this natural process enabled small numbers of RCWs to persist indefinitely.

Model Structure Weakness. There were a few components in the model that were not fully developed to show exact dynamics of the system. In these instances, the model structure or logic was assumed to simulate the actual system as best as possible. One of these areas was the movement dynamics of the cavity occupants. This is an extremely hard concept to model because a single cavity can have multiple residents in one year (McFarlane, 1992:106). Also the model did not fully develop the competition between the RCWs and SFSs for available vacant cavities. Vacant cavities were simply given to the RCW or SFS that needed it first. As mentioned previously, the SFS population was simply based off the number of pole hardwoods in an area. The exact SFS population dynamics are dependent upon many other variables.

The greatest weakness of the model was in its assumptions and intuitive parameter values. Theses values were hard to quantify in numerical terms. The model addressed these values by ranking them between 0.0 and 1.0 depending on their significance. The values were sensitivity tested; yet their true value may still be unknown. An example of one of these values was the Slash Pine Foraging Rating. The model assumed a relationship between the slash pine and the RCW foraging habitat. It is not entirely known if this relationship exists and/or its significance. However, the model structure showed how a Slash Pine Foraging Rating would be represented. Other major unknowns in the model were the index equations and the shape of graphical curves. Calibration of these model components was often left up to the modeler's intuition.

Software Limitations. The thesis model was designed to address spatial implications of the RCW habitat and RCW behavior. Therefore, the basic tree and RCW group structure was duplicated in multiple arrays. The STELLA software used to construct and simulate the model was not intended for models of the size developed in this thesis. The maximum amount of model entities that the STELLA software can compute in one time step is 32,767. The model ran up to this STELLA limit a few times during construction. The model size was necessary to include all of the twenty areas that the PWR was divided into. The model can be used to simulate other small RCW locations and populations. But the STELLA size limitations will not allow for further expansion of areas. Therefore, if the model is to be used with larger location sizes and RCW populations, the model logic will have to be reprogrammed to use fewer entities for each duplicating sector.

5. Findings and Conclusions

Meeting the Customer Requirement

Shaw AFB has the responsibility to manage the natural resources on the Poinsett Weapons Range (PWR). One of their management concerns is to determine optimal conversion rates from slash pine to longleaf pine on the PWR that would not adversely harm the range's RCW population due to habitat fragmentation. This question on optimal conversion rates became the customer requirement that guided the theory and logic applied during the model's construction. It was determined that a spatial and temporal model was needed to meet the customer requirement. The model developed was able to simulate the effect on the RCW population from different combinations of management strategies. Simulation results provide the customer insight on the probable effects to the PWR's RCW population from different management approaches.

Addressing Research Objective

1. Develop a spatially-explicit system dynamics model of the PWR RCW population that relates cooperative breeding behavior and foraging quality levels to the movement of individual birds and also incorporates various management inputs.

The model created for this thesis was able to incorporate the important spatial aspects of the system. Movement of RCWs within the PWR was based upon area foraging quality and RCW group status. Many of the common forest and RCW management practices were included as model inputs. The model was built specifically for the PWR ecosystem and included the current PWR forest and RCW data.

2. Explore the resultant behavior of the RCW population under different combinations of forest management and RCW management practices.

The model's general behavior responded as expected to the different combinations of forest management practices. The FM alternatives chosen for the model represented a range of forestry practices incorporated by forest managers. The fact that all of the FM alternatives produced relatively the same forest outcome indicated that there are many different ways to successfully manage a forest. Managers have the freedom to utilize the forest management strategy that best suits the resources available to them in order to meet their management goals. This is not to say that any combination of forest management practices will produce the same outcomes of the outlined FM alternatives. For example, suppression of fire for more than ten-year intervals or excessive silviculture thinnings will set back and ultimately degrade the forest conditions favorable to the RCW. The model showed that sensible forest management practices bring about the desired RCW forest. All five of the FM alternatives were used in the development of the RM alternatives.

The model behaved differently for the six RM alternatives simulated. It was obvious that some RCW management practices had a greater positive effect in the resultant RCW steady-state population level. The best RM practices were installing artificial cavities (RM Alternative 2) and translocating birds (RM Alternative 5). Interestingly, these two practices have been shown in the field to be the most productive in aiding struggling RCW populations. Another fascinating insight from the RM alternative simulations was the result of combining strategies together. RM Alternative 1 and Alternative 3, restrictor plate installment and SFS removal respectively, showed little

benefit to the RCW population when applied individually. However, collaboration of RM Alternatives 1, 2, and 3, which composed RM Alternative 4, created the greatest steady-state RCW population level of all six RM alternatives. The result indicated that synergy existed when applying multiple RCW management practices together. The population increases resulting from each individual RM alternative by themselves did not sum up to the population increase from RM Alternative 4 alone. This model discovery definitely encourages a RCW management strategy consisting of multiple techniques.

3. Determine the optimal rate, size, and layout of the conversion from slash pine to longleaf pine that does not adversely affect the short-term status of the RCW.

The thesis model, developed to address this particular question, simulated a range of conversion settings incorporated with different types of management strategies. The conversion settings ranged between various conversion frequencies and amounts per area. The results from the simulations were shown in Table 1. The data from Table 1 was rearranged in Table 2 to show the span of the different conversion setting outcomes for each RM alternative. The different conversion settings along with the result on the RCW population are listed in columns and for each RM alternative. The conversion settings were ordered in the respective RM alternative row from left to right, according to the most beneficial to the least desirable. The ordering methodology of the conversion settings for each RM alternative was as follows. First, transitional population behavior was arranged in the following order: continually growing (+), an initial decrease followed by an increase (- +), a decrease (-), and a crash (- -). Second, the resultant population level was arranged from largest to smallest. Last, the duration to complete the conversion from slash pine to longleaf pine on the PWR was arranged from the shortest

time to the longest time. The shaded conversions settings on the left side of the table resulted in outcomes that only increased the RCW population. The non-shaded conversion settings in the middle of the table resulted in outcomes that initially harmed the RCW population. The shaded conversion settings on the right side of the table resulted in outcomes that crashed the RCW population. According to the table in general, it would be advised to convert in an area no more than twenty acres at a time and to perform the conversions no less than every ten years.

Table 2: Ordered Conversion Settings for Each RM Alternative

RCW Management Alternatives																										
1	RCW	Transition Behavior	+	+	+	+	+	+	+	- +	- +	-	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
		Resultant SS Pop	35	35	30	30	30	30	25	30	25	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Conv.	Frequency [years]	15	10	10	10	5	15	15	5	5	15	5	5	5	5	10	10	5	15	10	15	10	15	10	15
		Amount [acreage]	15	5	15	10	5	10	5	15	10	20	40	35	30	25	40	35	20	40	30	35	25	30	20	25
		Completion [years]	270	500	185	260	275	375	700	110	150	200	65	70	80	90	90	95	100	100	105	120	125	140	150	175
2	RCW	Transition Behavior	+	+	+	+	+	+	+	+	- +	-	-	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
		Resultant SS Pop	55	55	55	55	50	50	50	50	30	10	10	0	0	0	0	0	0	0	0	0	0	0	0	0
	Conv.	Frequency [years]	10	15	10	15	10	15	15	5	10	15	15	5	5	5	5	10	10	5	15	10	5	15	10	5
		Amount [acreage]	10	10	5	5	15	20	15	5	20	30	25	40	35	30	25	40	35	20	40	30	15	35	25	10
		Completion [years]	260	375	500	700	185	200	270	275	150	140	175	65	70	80	90	90	95	100	100	105	110	120	125	150
3	RCW	Transition Behavior	+	+	+	+	- +	- +	- +	- +	-	-	-	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
		Resultant SS Pop	40	40	35	25	45	45	20	20	15	10	10	0	0	0	0	0	0	0	0	0	0	0	0	0
	Conv.	Frequency [years]	5	10	15	15	10	15	5	15	5	15	10	5	5	5	5	10	10	5	15	10	15	10	15	10
		Amount [acreage]	5	5	10	5	10	15	10	20	15	25	15	40	35	30	25	40	35	20	40	30	35	25	30	20
		Completion [years]	275	500	375	700	260	270	150	200	110	175	185	65	70	80	90	90	95	100	100	105	120	125	140	150
4	RCW	Transition Behavior	+	+	+	+	+	+	+	+	- +	- +	- +	- +	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
		Resultant SS Pop	85	85	85	85	85	85	85	80	80	70	70	60	0	0	0	0	0	0	0	0	0	0	0	0
	Conv.	Frequency [years]	10	15	10	15	5	15	15	10	10	15	15	5	5	5	5	5	10	10	5	15	10	5	15	10
		Amount [acreage]	15	20	10	15	5	10	5	5	20	30	25	10	40	35	30	25	40	35	20	40	30	15	35	25
		Completion [years]	185	200	260	270	275	375	700	500	150	140	175	150	65	70	80	90	90	95	100	100	105	110	120	125
5	RCW	Transition Behavior	+	+	+	+	+	+	+	+	- +	- +	- +	- +	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
		Resultant SS Pop	55	55	55	55	55	55	55	50	55	50	50	45	0	0	0	0	0	0	0	0	0	0	0	0
	Conv.	Frequency [years]	10	10	15	5	15	10	15	15	10	15	15	5	5	5	5	5	10	10	5	15	10	5	15	10
		Amount [acreage]	15	10	15	5	10	5	5	20	20	30	25	10	40	35	30	25	40	35	20	40	30	15	35	25
		Completion [years]	185	260	270	275	375	500	700	200	150	140	175	150	65	70	80	90	90	95	100	100	105	110	120	125
6	RCW	Transition Behavior	+	+	+	+	+	- +	-	-	-	-	-	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
		Resultant SS Pop	35	30	30	30	20	30	10	10	10	10	10	0	0	0	0	0	0	0	0	0	0	0	0	0
	Conv.	Frequency [years]	15	5	15	10	15	10	5	5	15	10	15	5	5	5	5	10	10	5	15	10	15	10	15	10
		Amount [acreage]	15	5	10	5	5	10	15	10	25	15	20	40	35	30	25	40	35	20	40	30	35	25	30	20
		Completion [years]	270	275	375	500	700	260	110	150	175	185	200	65	70	80	90	90	95	100	100	105	120	125	140	150

SS = Steady-State Conv. = Conversion

When actual conversions are done on the PWR, they will not be done in equal acreage amounts for set PWR areas according to a set rotating basis. Conversions will be

conducted on slash pine stands favorable to being converted. The location, amount cut, and conversion interval will not neatly match up with the data from Table 2. The table is intended to give the PWR managers probable outcomes for the different management alternatives. Managers should interpolate the table accordingly to the management alternative that best represents the management approach they wish to implement.

4. Improve the understanding and distinguish the mechanisms of the slash pine's role in the RCW's foraging habitat.

Longleaf pine is the preferred foraging tree of the RCW. When presented with the option of different pines to forage upon, the RCW selects longleaf pines the majority of the time. However, slash pines play a role in the overall foraging quality of areas composed of mixed pine stands. The degree to which the slash pine affects the RCW foraging habitat quality was explored during the development of the model. The Foraging Index created in the model incorporated the slash pine's contribution. The Slash Pine Foraging Rating determined its contribution as a percentage of the contribution that the longleaf pine provided to the Foraging Index equation. Initially, the rating was set at 0.5 during the calibration of the Foraging Index curve. The rating had a significant impact on the resultant steady-state of the Foraging Index (refer to Figure 58). After final model calibration, the Slash Pine Foraging Rating was tested again. The results showed that the Slash Pine Foraging Rating had minimal effect upon the resultant RCW population (refer to Figure 77). A possible reason for the population being unaffected by the Slash Pine Foraging Rating is that on the PWR, RCWs have the opportunity to forage on both longleaf and slash pines. Thus, when the Slash Pine Foraging Rating was dropped, the RCW population level was unaffected because the

RCWs would forage on the longleaf pines. When the Slash Pine Foraging Rating was high, the RCW population still remained the same because the RCWs would forage upon the longleaf pines due to its preference for longleaf pines.

Despite not providing a significant direct contribution to the Foraging Index, the slash pine provided indirect benefits to the foraging quality of an area. Slash pines stands can function as buffers for RCW foraging areas as well as habitat linkage corridors (Ferral, 1998:48-49). If the slash pine were to be removed, then the resulting clear-cuts would fragment the RCW foraging habitat. This occurrence was accounted for by the Fragmentation Index, which was incorporated in the model's Foraging Index equation. The slash pine does not directly affect the model's Foraging Index; however the absence of the slash pines did impact the Foraging Index.

Comparison to Other Findings

There are no spatial/temporal models that incorporate the habitat fragmentation effects of slash pine to longleaf pine conversion. However, there have been many field studies performed exploring the effects on RCW populations to conversion and habitat fragmentation. Most of these studies indicated some impact to the RCW population in the short-term. A majority of RCW models showed that large population sizes are needed to ensure the population's resilience to stochastic environmental impacts and prevent loss of heterozygosity to genetic drift. Stevens, in two different models, predicted respectively that 556 and 1,200 RCWs were needed to maintain a population's long-term viability. Steven's models were based on genetic and environmental variability considerations (Stevens, 1995:227). Reed and Walters calculated minimum viable RCW population sizes based on genetic variability. The calculations showed that

an at least 509 breeding pairs, resulting in a census size of 1,323 individuals (including fledglings), were needed to maintain a viable RCW population (Reed et al., 1988:388).

Letcher, Priddy, Walters, and Crowder predicted that highly dense populations with 25 groups in 49 territories could sustain itself. The Letcher model took into account initial population size, density, and group spacing but did not correlate the spatial quality of the habitat (Letcher et al., 1998:1). Further study and development of the Letcher model by Crowder, Priddy, and Walters showed that a few number of individuals in closely packed groups were enough to maintain a RCW population in the short-term. When the Crowder model was set for an initial population of five aggregated groups, similar to the PWR RCW population, the model should that the population on average became extinct in seventeen years. This simulation did not take into account progressive management techniques; however, it assumed only minimal management similar to RM Alternative 6. The Crowder model simulations also showed the number of annual immigrations into a population that were necessary to keep population viability. The five aggregated groups previously mentioned required two immigrants per year for sustainment (Crowder et al., 1998:1-15). Thus, this illustrates how intensive management, such as translocations, can keep even the smallest RCW populations stable. This has been the case with the PWR RCW population. The thesis model was developed under this notion of small RCW population sustainability.

Viable Model Use

The thesis model is only valid under the assumptions incorporated in its logic. Any conclusions made from the model simulations must be sure to address these assumptions. The model should be used only on small RCW populations under 100 birds

and on areas under 10,000 acres. Also, current timber and RCW databases with appropriate model input data is required. The model can give predictions on possible outcomes from different management strategies. It is recommended that only management strategies showing a resultant increase in the RCW population be used, similar to the strategies highlighted on the left side of Table 2. However, the resultant RCW populations are only model estimations. If the thesis model's results are used in the development of a RCW management plan, the model's assumptions must be taken into consideration. Strategies that are shown to initially harm the RCW population in Table 2 should be avoided because of the potential extirpation of the population.

Suggestions for Further Study

Recommended follow-on efforts for this thesis would be the continued development of the model. The STELLA file size constraints limit the maximum RCW location size that can be effectively modeled. Reprogramming the same logic in the model structure, by using a more efficient file-size approach, would enable the model to incorporate more than twenty potential RCW areas. This would expand the applicable use of the model for larger RCW habitat locations. Another area in which to improve the model is in the further development of the model's indexes and unknown parameters. Testing and calibration was performed on these variable values to show theoretical model behavior. However, a full understanding of the model indexes and unknown parameters was not obtained. Results showed that the model was particularly sensitive to the index values. Therefore, additional research in the mechanisms and logic that define various levels represented by different model indexes would create a more accurate model. One last area that could be incorporated into the model is the concept of genetic drift. Though

it would be hard to include in the model, genetic drift is a complex reality that can negatively affect RCW population levels. However small RCW populations are able to persist despite genetic loss. Exploration on how genetic drift affects RCW populations would be a challenging modeling effort.

Further use of the model includes comparison of model output to actual RCW population data. The model output can be compared with past population trends from small RCW populations, as long as the RCW and forestry records were kept from the respective location. In the future, the model output can be compared with the actual RCW population level on the PWR. A variation of the model use can be to incorporate economic life-cycle assessments on different possible forest and RCW management strategies.

Appendix A: Model Input Data

Glossary

Artificial Cavity Insert: Rectangular nest box inserted into similar shaped cut made in older pine trees

Breeding Pair: RCW male and female that mate and produce RCW offspring

Cavity: Cylinder-shaped nesting chamber excavated by RCWs in the heartwood of old-growth pine trees

Cavity Drilling: RCW management technique used to begin or create cavities

Cavity Restrictor Plate: Square metal sheet with a U-shaped slit in the diameter of a RCW cavity entrance hole – plate is placed over cavity entrance hole to prevent enlargement from other woodpeckers

Cavity Tree: Old-growth pine tree containing RCW cavities

Cleat-Cut: Timber harvest practice of cutting every tree down in a specific area

Cluster: Arrangement of neighboring cavity trees that supports or can potentially support a RCW group

Cooperative Breeding: Social and reproductive behavior in which species live together in groups – certain individuals in the group forego breeding to assist in the raising of the group breeding pair's young

Conversion: Management practice of converting off-site trees back to native trees

Foraging Habitat: Acreage of pine trees at least thirty years old that RCWs forage upon

Group: Consists of at least a RCW breeding pair and may also included the breeding pairs nestlings or fledglings as well as helper RCWs – they all reside in a cluster of cavity trees

Helper: Typically a male RCW offspring from the group's breeding pair that stays with the group to assist in the rearing of the breeding pair's young

Herbicide: Chemicals administered to trees in order to kill the tree

Home Range: Land area containing the RCW group's cavity tree cluster and the trees that the group forages upon – RCWs in the group will defend their area from neighboring RCW groups

Large Pole Pine Age Class: Model pine tree age class consisting of pine trees aging from 30 to 60 years

Mature Pine Age Class: Model pine tree age class consisting of pine trees aging from 60 to 90 years

Native Species: Species that naturally exist in a geographic area – species has adapted to the conditions of the particular area

Off-site Species: Species that is not native to a geographic area – often introduced into areas

Old-Growth Pine Age Class: Model pine tree age class consisting of pine trees over the age of 90 years

Prescribed Burn: Controlled fires set to replicate the natural fire effects on ecosystems

Sapling Pine Age Class: Model pine tree age class consisting of pine trees aging from 1 to 15 years

Seedling Pine Age Class: Model pine tree age class consisting of pine trees in their initial seedling grass stage

Silviculture: Timber harvesting practice used to create the desired tree class density for each tree age class

Small Pole Pine Age Class: Model pine tree class consisting of pine trees aging from 15 to 30 years

Squirrel Box: Nesting box attached to trees that are used to capture squirrels

Translocation: Practice of introducing RCWs from healthy populations into other RCW populations – used to spread genetic traits and support ailing populations

Acronyms

AFB: Air Force Base
DoD: Department of Defense
dbh: Diameter at Breast Height
FM Alt: Forest Management Alternative
NMFS: National Marine Fisheries Service
PWR: Poinsett Weapons Range
RCW: Red-Cockaded Woodpecker
RM Alt: RCW Management Alternative
SFS: Southern Flying Squirrel
SNED: Snake Excluder Device
SPB: Southern Pine Beetle
SQED: Squirrel Excluder Device
USDA: United States Department of Agriculture
USFS: United States Forest Service
USFWS: United States Fish and Wildlife Service

Map Information

The methodology used to divide up the PWR areas was outlined in Chapter 3 under the Model Data heading. Described next is information pertaining to particular features of the PWR map, shown in Figure 78.

1. The different area shades are only for distinguishing the areas from one another.
2. Cavity trees are represented by white squares.
3. The wetland areas and bombing range areas are labeled and left blank.
4. The patches of lands to east of the wetlands contain pine trees but due to their segregation from the majority of the PWR forested land, they were not considered to be potential RCW habitat areas.
5. Residential and private lands make up the eastern boundary of the PWR.
6. The Manchester State Forest makes up the entire western border of the PWR.
7. Area 20 is divided by the boundary between the PWR and Manchester State Forest. The Manchester State Forest land was included due to the RCW use of cavity trees on the state forest. The area of Manchester State Forest included in Area 20 was set to only encompass the cavity trees on the state forest.

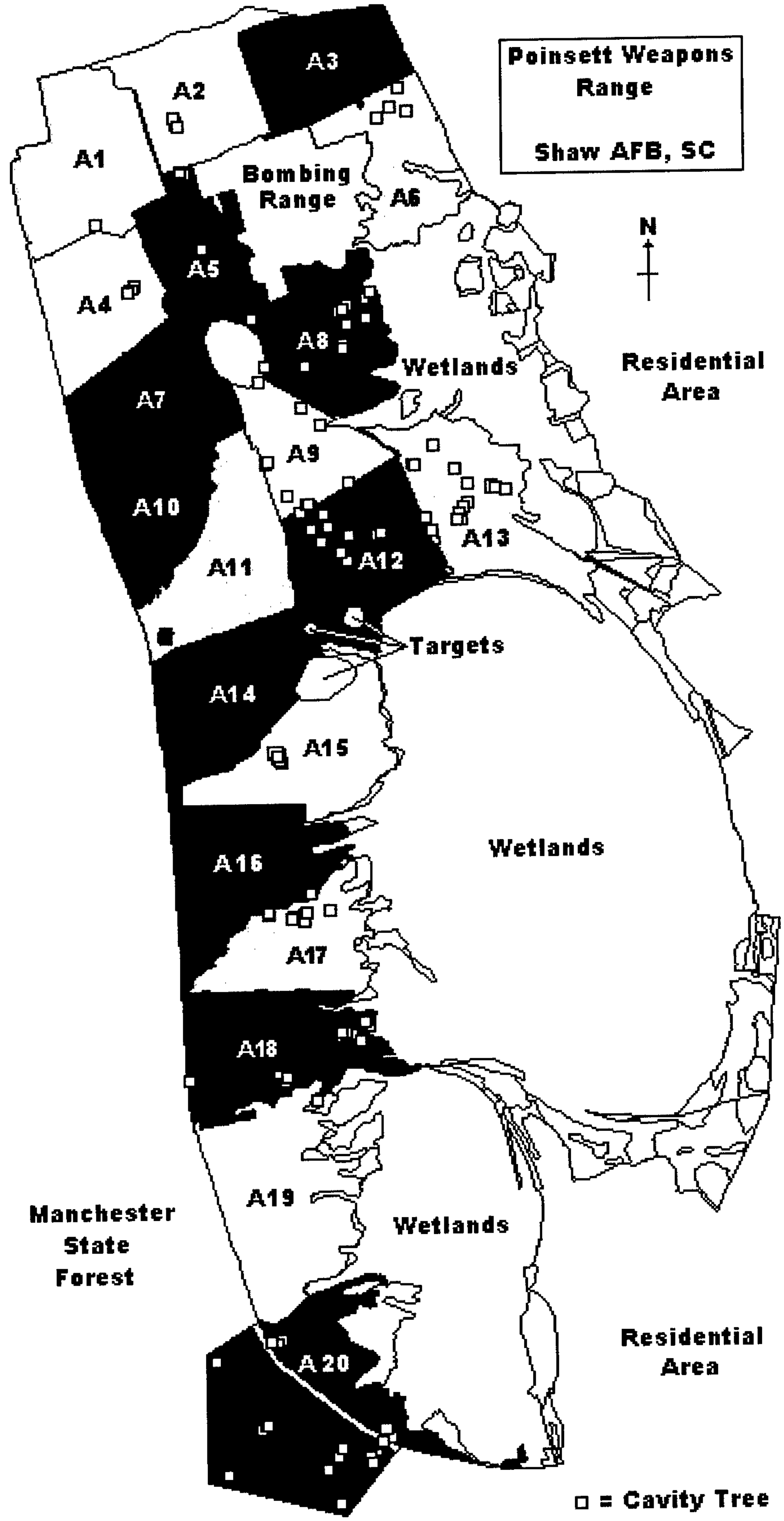

Figure 78: Poinsett Weapons Range Area Map

Table 3 and Table 4 Information

The input data used for the model was obtained from the Shaw AFB's GIS database and field reports. Model entities without actual data from the PWR used plausible input values. Table 3 and Table 4 contain the tabulated model input data. Described next is information pertaining to how the raw data was interrupted for use by the model and how the data was represented in the Table 3 and Table 4.

1. The number of RCW adults and fledglings for each group was obtained from Shaw AFB. All groups were assumed to contain a breeding male and female. Excess birds were assumed to be male helpers. The ages of the RCW adults were logically assumed and were distributed between one and six years of age. The sex of the fledglings was also logically assumed.
2. The amount of acreage for each area containing either longleaf pine or slash pine, as well as acreage clear-cut or replanted, was obtained from the GIS data on tree stand categorization.
3. The small amount of acreage on the PWR containing loblolly pine and sand pine was considered in the model to be slash pine acreage.
4. Manchester State Forest acreage included in Area 20 was estimated using GIS map scales. The tree composition of the Manchester State Forest in Area 20 was assumed and calculated by using the same proportion of longleaf pine and slash pine found in Area 20 on PWR.
5. The number of SFS adults in each area was assumed and calculated using the number of pole size hardwood trees in the respective area (one SFS per every 600 pole size

hardwood trees). The number of adolescent SFSs in each area was assumed to be half of the number of adults in the respective area.

6. The number of cavities in each area was obtained from the GIS data. The status of the cavities in each was assumed and categorized using the following methodology. First, RCW occupied cavities were set to equal the number of RCWs in the respective area. Second, SFS occupied cavities were set to equal a plausible amount relative to the number of SFSs in the respective area. Third, the remaining cavities were distributed between the vacant and degraded cavity categories. It was assumed that there are more vacant cavities than degraded cavities.

7. In each area, the number of pulpwood pine trees and saw timber pine trees for both the slash pine and longleaf pine was obtained from the GIS data. The pulpwood classification includes trees with dbh's from 4 to 9 inches. In each area, it was assumed that the number of trees in the small pole pine age class was 66% of the area's respective number of pulpwood trees. It was also assumed in each area that the number of trees in the large pole pine age class was 33% of the area's respective number of pulpwood trees. The division of pulpwood trees into the small pole pine and large pole pine age categories was the same for both slash pines and longleaf pines. The saw timber classification includes trees with dbh's 9 inches and above. For each area, the number of trees in the mature slash pine age category was assumed to be the same as the number of saw timber slash pine trees in the respective area. It was assumed in each area that the number of trees in the mature longleaf pine age class was 66% of the area's respective number of saw timber longleaf pine trees. The model also assumed in each area that the number of

trees in the old-growth longleaf pine age class was 33% of the area's respective number of saw timber longleaf pine trees.

8. It was assumed in each area that the seedling density and sapling density was 500 and 200 per acre respectively for both longleaf pine and slash pine. If an area did not include pines as old as the pulpwood classification or older, then it was assumed that seedlings and saplings did not exist on the respective area for the respective pine type.

9. As with the pine type acreage division of the Area 20 land on the Manchester State Forest, the amount of each pine type and age breakout was proportional to the amounts found in Area 20's PWR forest stands.

11. The number of pulpwood hardwood trees was obtained from the GIS data for each area. Pulpwood hardwoods include trees with a dbh greater than 4 inches and at least 20 feet tall. The pole size hardwood age class included the same number of trees as in the pulpwood hardwood in the respective area. The hardwood sapling density was assumed to be 50 saplings per acre.

12. For each area, the density of trees per acre in each age class was given for comparison purposes.

Table 3: Poinsett Weapons Range Input Data

RCW	1	2	3	4	5	6	7	8	9	Area 10	11	12	13	14	15	16	17	18	19	20	Range Total	Manchester State Forest	Area 20 Total
Males	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	1	5	0	1
Age	-	4	-	-	-	-	-	4	-	-	-	5	-	-	-	-	3	-	-	5	-	-	5
Helpers	0	1	0	0	0	0	0	1	0	0	0	2	0	0	0	0	1	0	0	1	6	0	1
Age	-	1	-	-	-	-	-	1	-	-	-	1/2	-	-	-	-	2	-	-	1	-	-	1
Females	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	1	5	0	1
Age	-	3	-	-	-	-	-	2	-	-	-	4	-	-	-	-	3	-	-	3	-	-	3
Fledglings	0	2	0	0	0	0	0	1	0	0	0	1	0	0	0	0	2	0	0	3	9	0	3
Sex	-	M/F	-	-	-	-	-	M	-	-	-	F	-	-	-	-	M/F	-	-	M/2F	4M/5F	-	M/2F
Adult Total	0	3	0	0	0	0	0	3	0	0	0	4	0	0	0	0	3	0	0	3	16	0	3
Total	0	5	0	0	0	0	0	4	0	0	0	5	0	0	0	0	5	0	0	6	25	0	6

Acreage	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	PWR	Manchester	A20 Tot
Slash	155	25	5	150	10	85	215	0	0	110	240	75	120	195	175	220	40	130	240	50	2240	90	140
Longleaf	180	255	240	100	230	155	45	255	195	140	75	230	215	110	150	130	155	120	180	120	3280	210	330
Longleaf Seed	5	0	0	0	5	0	0	20	0	0	0	0	0	0	0	0	0	75	10	45	160	0	45
Clearcut	0	0	10	0	0	0	15	0	0	10	0	20	0	0	0	0	20	0	0	5	80	0	5
Total Acreage	340	280	255	250	245	240	275	275	195	260	315	325	335	305	325	350	215	325	430	220	5760	300	520

SFS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	PWR	Manchester	A20 Tot
Young	5	4	0	1	4	0	5	1	2	5	4	0	3	2	1	3	1	0	2	0	41	0	0
Adults	10	8	0	1	9	0	10	1	4	9	8	0	5	4	2	6	2	1	4	0	82	0	0

Cavities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	PWR	Manchester	A20 Tot
RCW Cavities	0	3	0	0	0	0	0	3	0	0	0	4	0	0	0	0	3	0	0	3	16	0	3
SFS Cavities	0	1	0	0	2	0	0	0	2	0	2	0	3	0	1	0	1	1	0	0	13	0	0
Vacant Cavities	1	0	0	3	2	3	0	7	6	0	0	6	8	0	6	1	4	10	1	4	76	14	18
Degraded Cavities	0	0	0	0	1	1	0	2	2	0	0	2	2	0	2	0	2	4	0	2	27	7	9
Tot Cavity Trees	1	4	0	3	5	4	0	12	10	0	2	12	13	0	9	1	10	15	1	9	132	21	30

Table 4: Poinsett Weapons Range Timber Input Data

Acreage	Area 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Range Total	Manchester State Forest	Area 20 Total
Slash	155	25	5	150	10	85	215	0	0	110	240	75	120	195	175	220	40	130	240	50	2240	90	140
Longleaf	180	255	240	100	230	155	45	255	195	140	75	230	215	110	150	130	155	120	180	120	3280	210	330
Longleaf Seed	5	0	0	0	5	0	0	20	0	0	0	0	0	0	0	0	0	75	10	45	160	0	45
Clearcut	0	0	10	0	0	0	15	0	0	10	0	20	0	0	0	0	20	0	0	5	80	0	5
Total Acreage	340	280	255	250	245	240	275	275	195	260	315	325	335	305	325	350	215	325	430	220	5760	300	520

Slash Pine	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	PWR	Manchester	A20 Tot
SL Pulpwood	37700	10	100	17400	1700	27800	28200	0	0	17300	51400	14300	24100	31000	34000	62300	6600	15200	45000	7500	421610	13500	21000
SL Saw Timber	2600	100	50	4700	300	400	5500	0	0	1400	3600	3100	3600	7500	7100	6000	1800	7400	9400	2800	67350	5040	7840
SL Pulp Ave/Acre	243	0	20	116	170	327	131	0	0	157	214	191	201	159	194	283	165	117	188	150	188	150	150
SL Saw Ave/Acre	17	4	10	31	30	5	26	0	0	13	15	41	30	38	41	27	45	57	39	56	30	56	56

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	PWR	Manchester	A20 Tot
SL Seedling	77500	1000	500	75000	5000	42500	107500	0	0	55000	120000	37500	60000	97500	87500	110000	20000	65000	120000	25000	1106500	45000	70000
SL Sapling	31000	500	250	30000	2000	17000	43000	0	0	22000	48000	15000	24000	39000	35000	44000	8000	26000	48000	10000	442750	18000	28000
SL Small Pole	24882	7	66	11484	1122	18348	18612	0	0	11418	33924	9438	15906	20460	22440	41118	4356	10032	29700	4950	278263	8910	13860
SL Large Pole	12818	4	34	5916	578	9452	9588	0	0	5882	17476	4862	8194	10540	11560	21182	2244	5168	15300	2550	143348	4590	7140
SL Mature	2600	100	50	4700	300	400	5500	0	0	1400	3600	3100	3600	7500	7100	6000	1800	7400	9400	2800	67350	5040	7840
SL Sap / Acre	500	40	20	500	500	500	500	0	0	500	500	500	500	500	500	500	500	500	500	500	494	500	500
SL Seed / Acre	200	20	10	200	200	200	200	0	0	200	200	200	200	200	200	200	200	200	200	200	198	200	200
SL SPole / Acre	161	0	13	77	112	216	87	0	0	104	141	126	133	105	128	187	109	77	124	99	124	99	99
SL LPole / Acre	83	0	7	39	58	111	45	0	0	53	73	65	68	54	66	96	56	40	64	51	64	51	51
SL Mature / Acre	17	4	10	31	30	5	26	0	0	13	15	41	30	38	41	27	45	57	39	56	30	56	56

Longleaf Pine	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	PWR	Manchester	A20 Tot
LLF Pulpwood	23900	8500	9500	25600	11500	14200	7000	2200	4400	43200	4200	5800	3400	20100	19700	10200	6900	4900	21200	14000	260400	24500	38500
LLF Saw Timber	10800	4100	3700	1400	8200	2800	1300	9500	3800	2800	2600	5000	5800	1800	10400	4100	5400	5300	8100	4800	101700	8400	13200
LLF Pulp Ave/Acre	133	33	40	256	50	92	156	9	23	309	56	25	16	183	131	78	45	41	118	117	79	117	117
LLF Saw Ave/Acre	60	16	15	14	36	18	29	37	19	20	35	22	27	16	69	32	35	44	45	40	31	40	40

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	PWR	Manchester	A20 Tot
LLF Seedling	90000	127500	120000	50000	115000	77500	22500	127500	97500	70000	37500	115000	107500	55000	75000	65000	77500	60000	90000	60000	1640000	105000	165000
LLF Sapling	36000	51000	48000	20000	46000	31000	9000	51000	39000	28000	15000	46000	43000	22000	30000	26000	31000	24000	36000	24000	656000	42000	66000
LLF Small Pole	15774	5610	6270	16896	7590	9372	4620	1452	2904	28512	2772	3828	2244	13266	13002	6732	4554	3234	13992	9240	171864	16170	25410
LLF Large Pole	8126	2890	3230	8704	3910	4828	2380	748	1496	14688	1428	1972	1156	6834	6698	3468	2346	1666	7208	4760	88536	8330	13090
LLF Mature	7128	2706	2442	924	5412	1848	858	6270	2508	1848	1716	3300	3828	1188	6864	2706	3564	3498	5346	3168	67122	5544	8712
LLF Old-Growth	3672	1394	1258	476	2788	952	442	3230	1292	952	884	1700	1972	612	3536	1394	1836	1802	2754	1632	34578	2856	4488
LLF Seed / Acre	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
LLF Sap / Acre	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
LLF SPole / Acre	88	22	26	0	33	60	103	6	15	204	37	17	10	121	87	52	29	27	78	77	52	77	77
LLF LPole / Acre	45	11	13	87	17	31	53	3	8	105	19	9	5	62	45	27	15	14	40	40	27	40	40
LLF Mature / Acre	40	11	10	9	24	12	19	25	13	13	23	14	18	11	46	21	23	29	30	26	20	26	26
LLF OG / Acre	20	5	5	5	12	6	10	13	7	7	12	7	9	6	24	11	12	15	15	14	11	14	14

Hardwoods	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	PWR	Manchester	A20 Tot
Hardwood Sapling	17000	14000	12750	12500	12250	1200	13750	13750	9750	13000	15750	16250	16750	15250	16250	17500	10750	16250	21500	11000	277200	15000	26000
Hardwood Pole	6000	4800	0	700	5100	20	5800	600	2200	5500	4700	200	3000	2300	1200	3800	900	400	2100	0	266200	0	0
HW Sapling / Acre	50	50	50	50	50	5	50	50	50	50	50	50	50	50	50	50	50	50	50	50	49420	50	50
HW Pole / Acre	18	17	0	3	21	0	21	2	11	22	15	1	9	8	4	11	4	1	5	0	46	0	0

Table 5: Poinsett Weapons Range Corridor Ratings

Area	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0	1	0.75	1	1	0.5	0.5	0.5	0.25	0.25	0.25	0	0	0	0	0	0	0	0	0
2	1	0	1	0.75	1	0.75	0.5	0.25	0.25	0.25	0	0	0	0	0	0	0	0	0	0
3	0.75	1	0	0.25	0.75	1	0.25	0.25	0	0	0	0	0	0	0	0	0	0	0	0
4	1	0.75	0.25	0	1	0	1	0.75	0.75	0.75	0.5	0.25	0	0.25	0	0	0	0	0	0
5	1	1	0.75	1	0	0.25	1	1	0.75	0.75	0.5	0.5	0.25	0.25	0	0	0	0	0	0
6	0.5	0.75	1	0	0.25	0	0	0.75	0.25	0	0	0	0	0	0	0	0	0	0	0
7	0.5	0.5	0.25	1	1	0	0	0.75	1	1	1	0.75	0.5	0.5	0.25	0	0	0	0	0
8	0.5	0.25	0.25	0.75	1	0.75	0.75	0	1	0.75	0.75	0.75	0.75	0.5	0.25	0	0	0	0	0
9	0.25	0.25	0	0.75	0.75	0.25	1	1	0	1	1	1	1	0.75	0.5	0.25	0	0	0	0
10	0.25	0.25	0	0.75	0.75	0	1	0.75	1	0	1	0.75	0.5	0.75	0.5	0.25	0	0	0	0
11	0.25	0	0	0.5	0.5	0	1	0.75	1	1	0	1	0.75	1	0.75	0.5	0.25	0	0	0
12	0	0	0	0.25	0.5	0	0.75	0.75	1	0.75	1	0	1	1	1	0.75	0.5	0.25	0	0
13	0	0	0	0	0.25	0	0.5	0.75	1	0.5	0.75	1	0	0.75	0.5	0.25	0	0	0	0
14	0	0	0	0.25	0.25	0	0.5	0.5	0.75	0.75	1	1	0.75	0	1	1	0.5	0.25	0	0
15	0	0	0	0	0	0	0.25	0.25	0.5	0.5	0.75	1	0.5	1	0	1	0.75	0.5	0.25	0
16	0	0	0	0	0	0	0	0	0.25	0.25	0.5	0.75	0.25	1	1	0	1	1	0.5	0
17	0	0	0	0	0	0	0	0	0	0	0.25	0.5	0	0.5	0.75	1	0	1	0.75	0.25
18	0	0	0	0	0	0	0	0	0	0	0	0.25	0	0.25	0.5	1	1	0	1	0.5
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.25	0.5	0.75	1	0	1
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.25	0.5	1	0

Appendix B: Influence and Flow Diagrams

Influence Diagrams

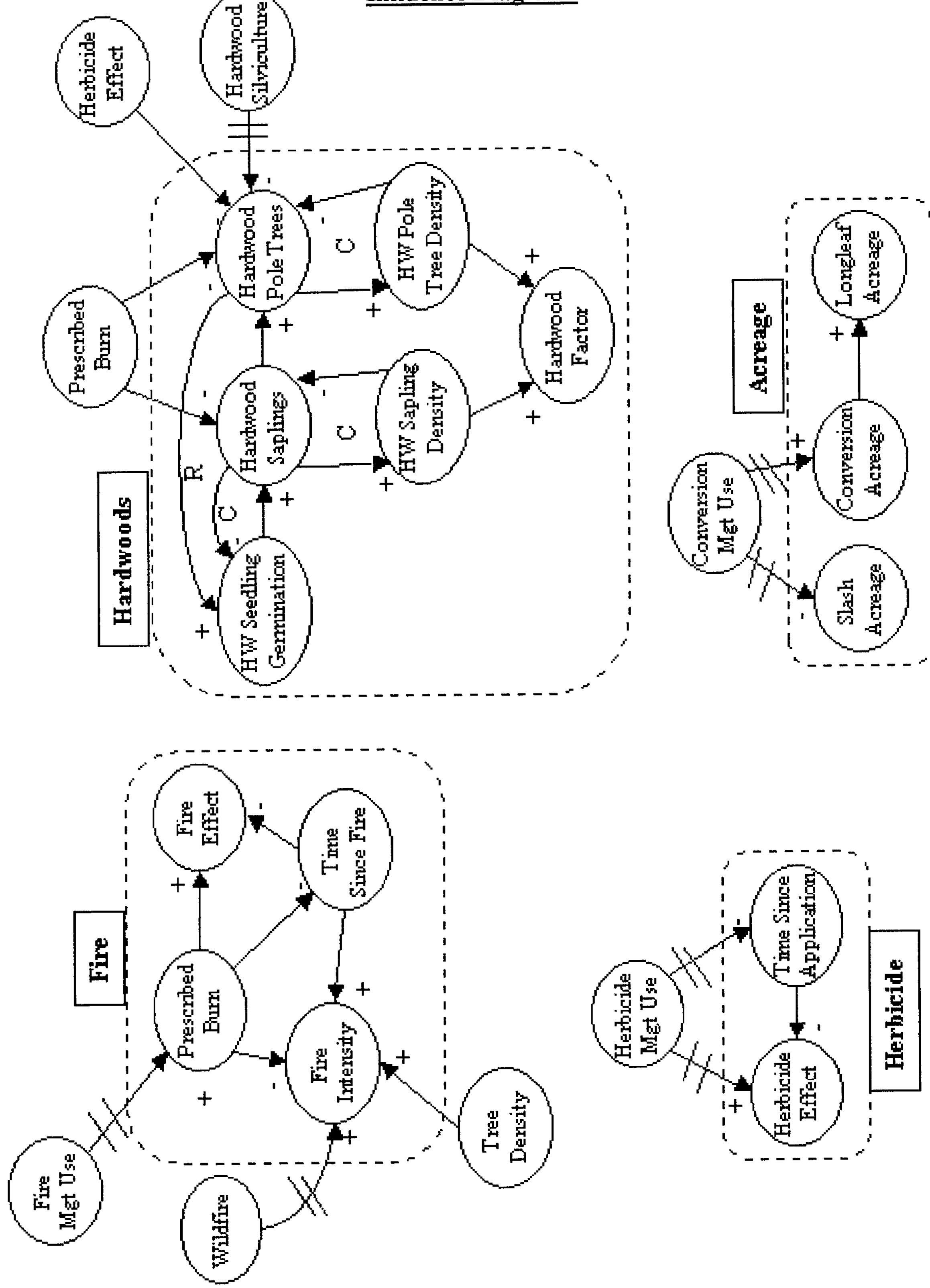

Figure 79: Detailed Influence Diagram: Fire, Hardwoods, Herbicide, and Acreage Sectors

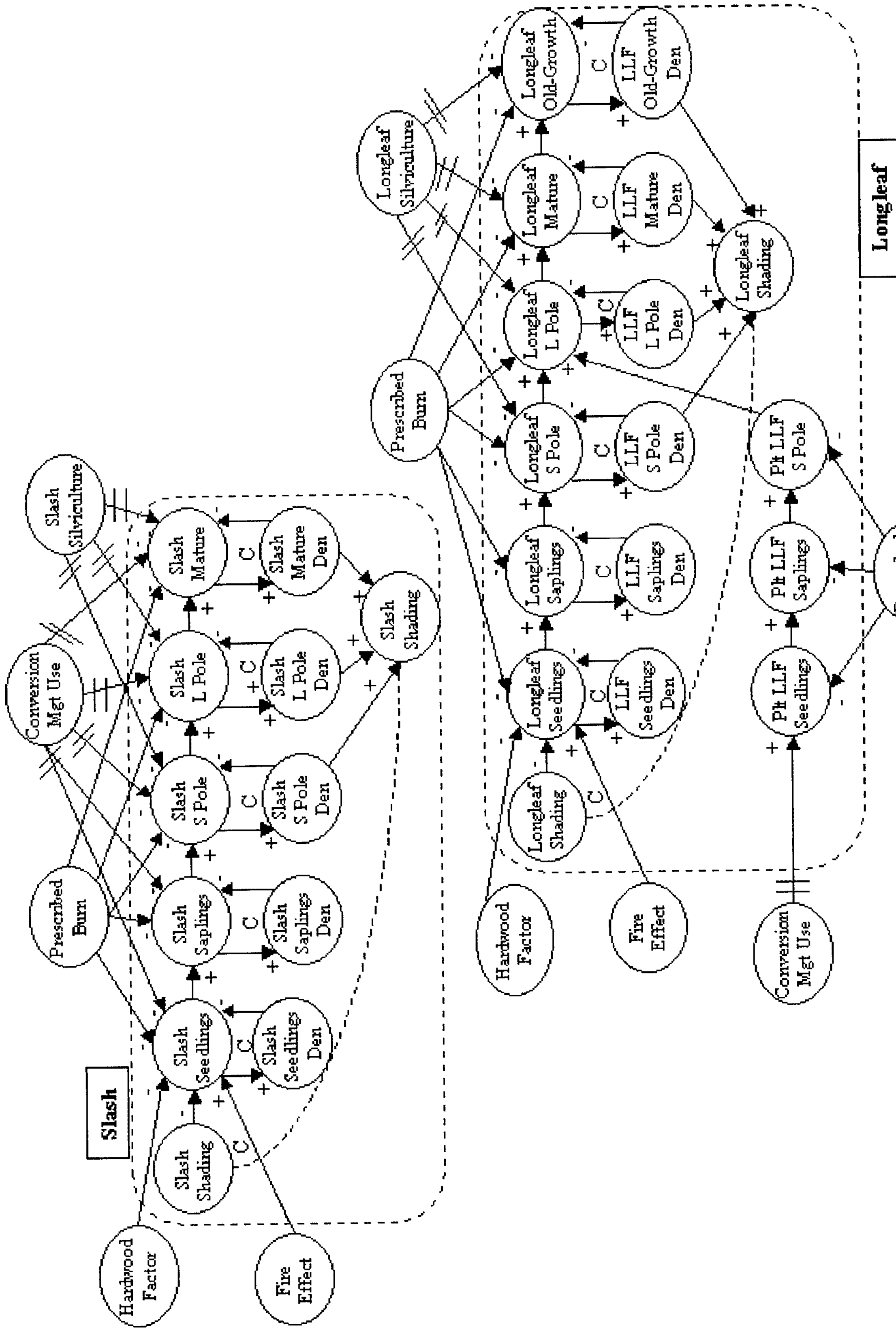

Figure 80: Detailed Influence Diagram: Slash Pine and Longleaf Pine Sectors

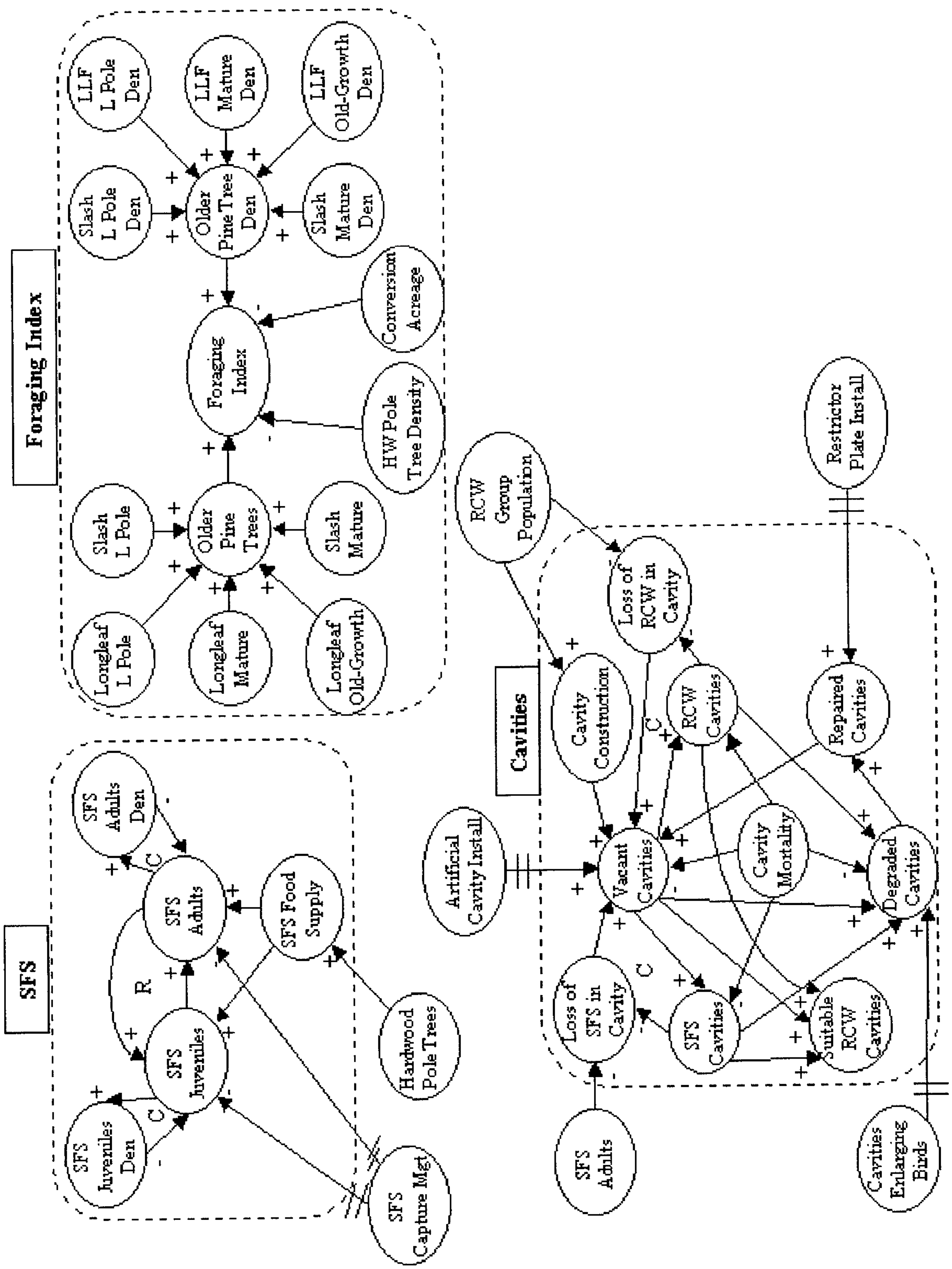

Figure 81: Detailed Influence Diagram: SFS, Foraging Index, and Cavities Sectors

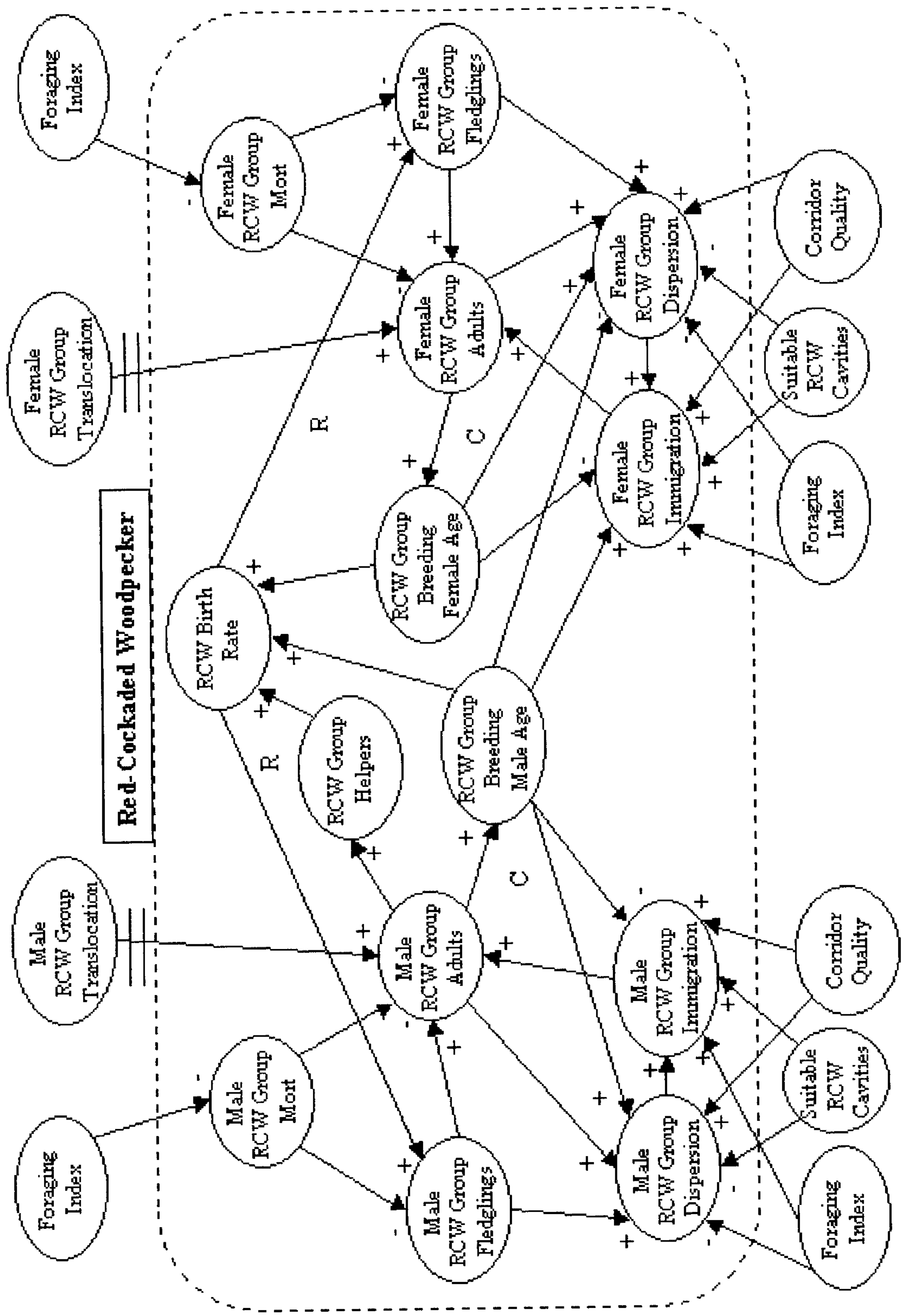

Figure 82: Detailed Influence Diagram: Red-Cockaded Woodpecker Sector

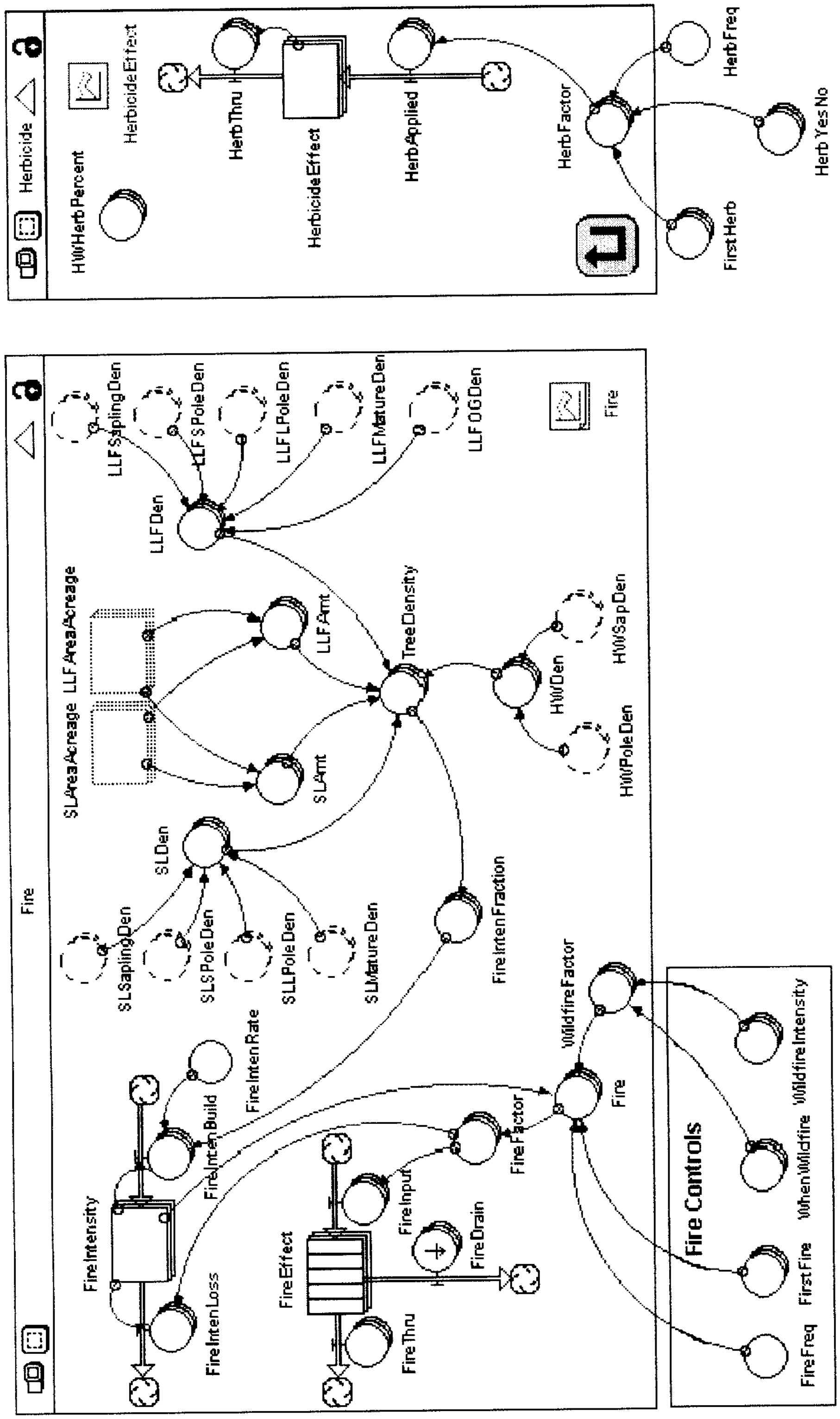

Figure 83: Flow Diagram: Fire and Herbicide Sectors

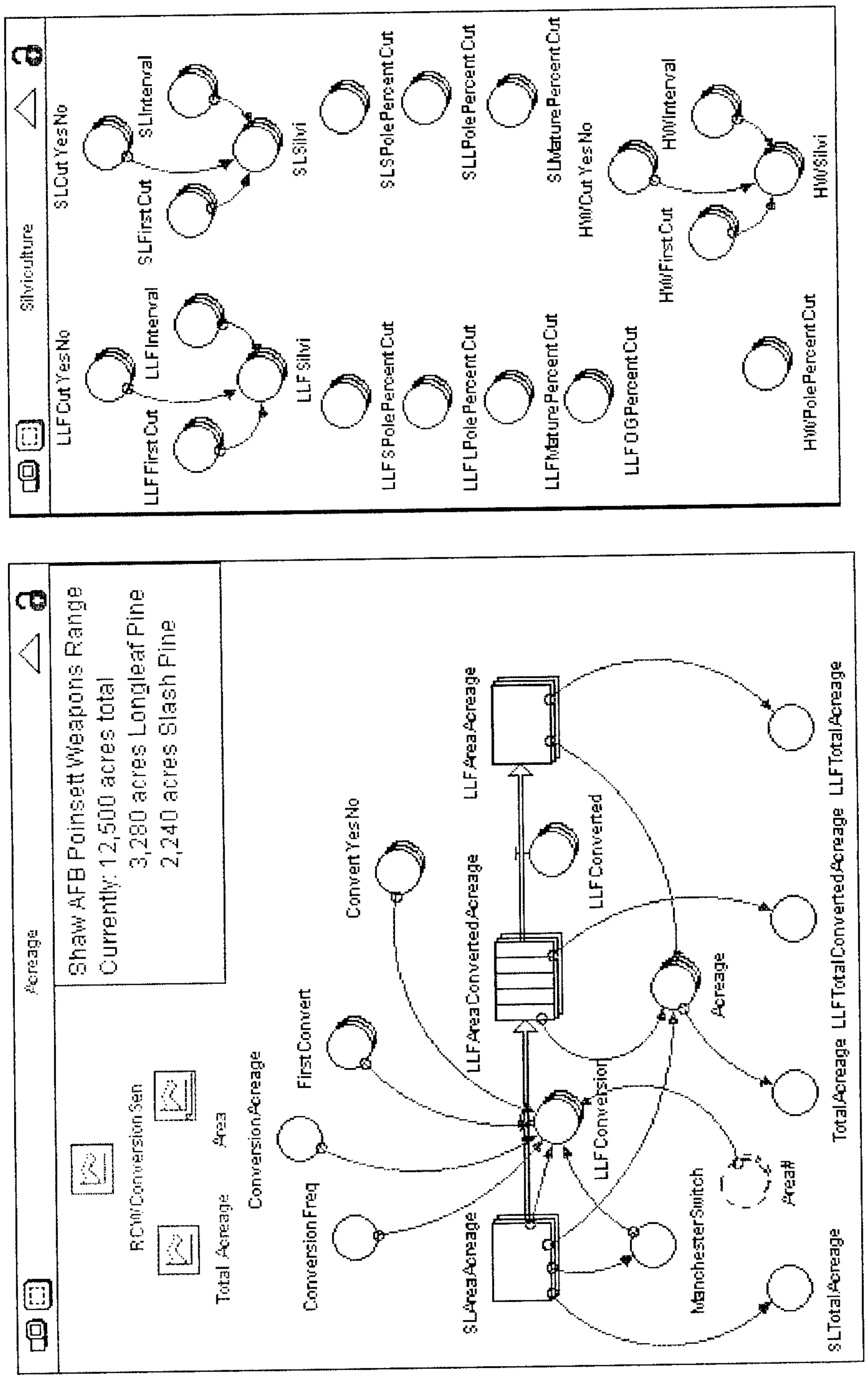

Figure 84: Flow Diagram: Acreage and Silviculture Sectors

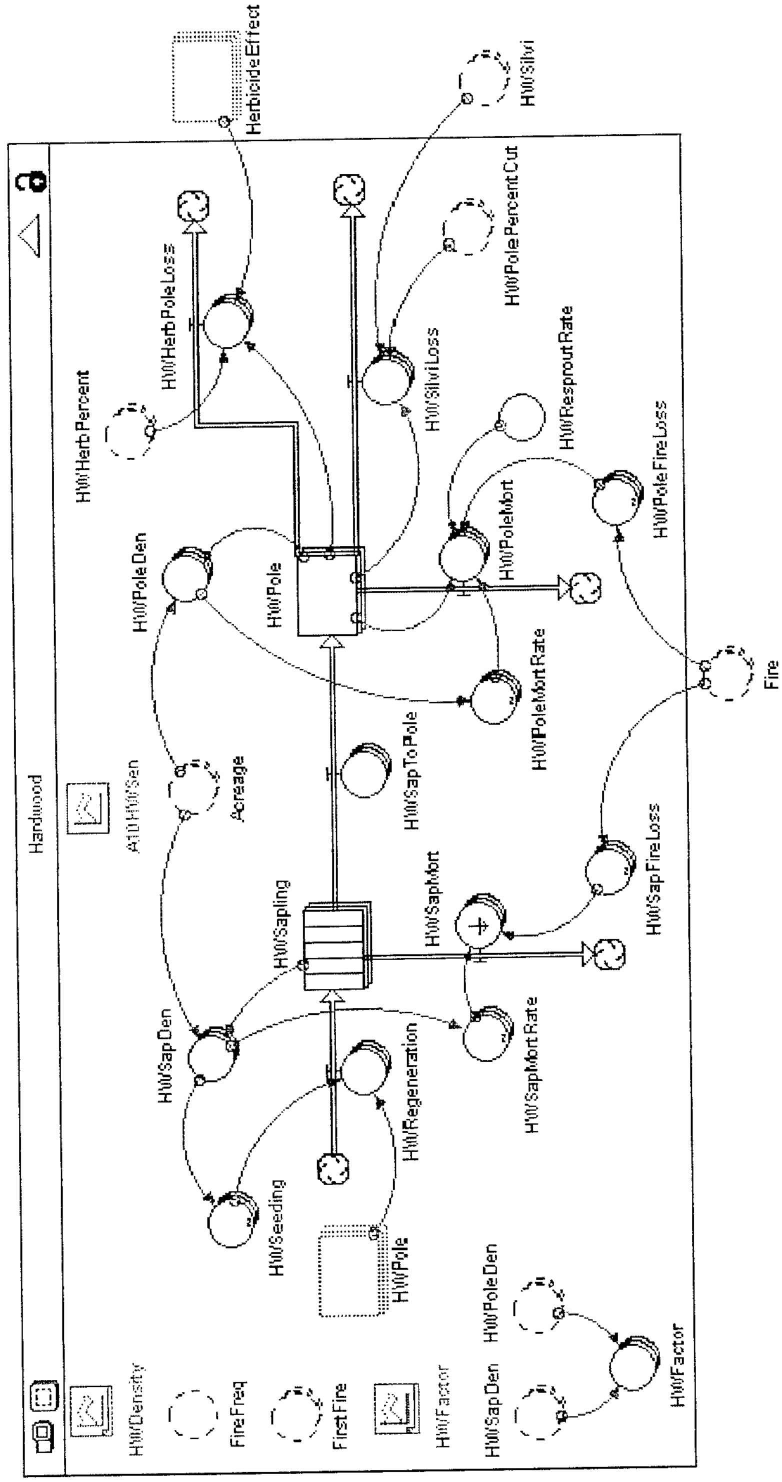

Figure 85: Flow Diagram: Hardwood Sector

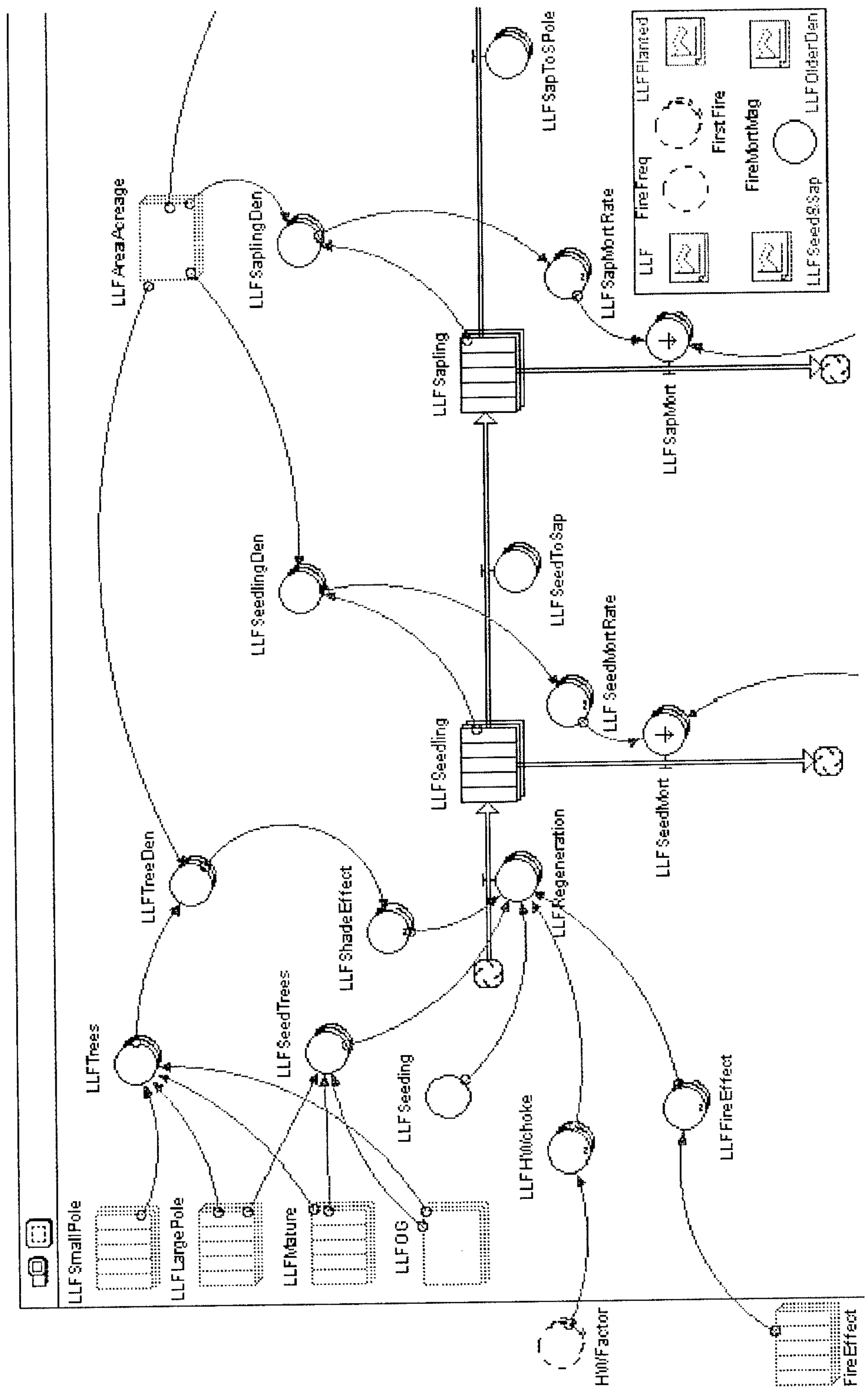

Figure 86: Flow Diagram: Longleaf Pine Sector (Part 1 of 4)

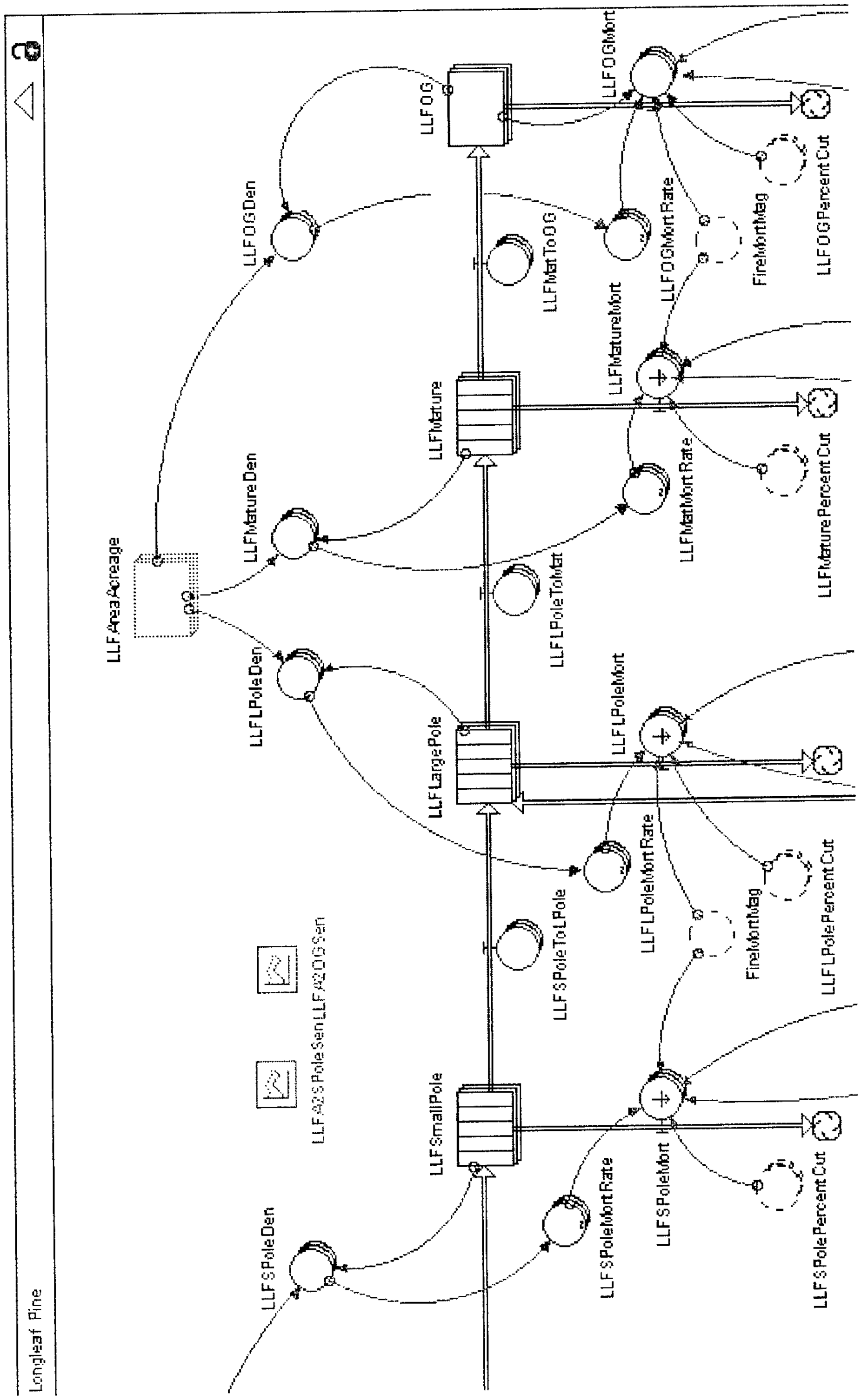

Figure 87: Flow Diagram: Longleaf Pine Sector (Part 2 of 4)

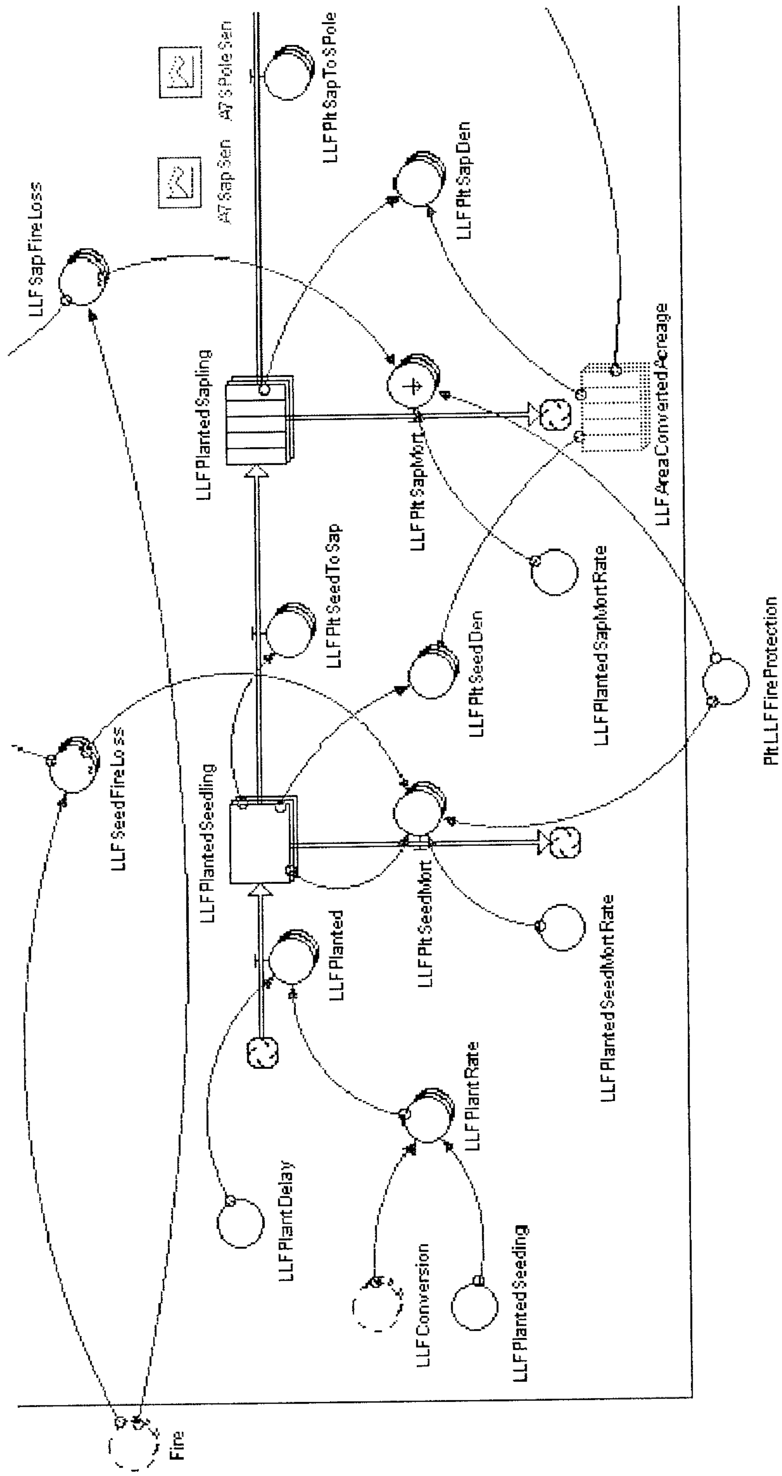

Figure 88: Flow Diagram: Longleaf Pine Sector (Part 3 of 4)

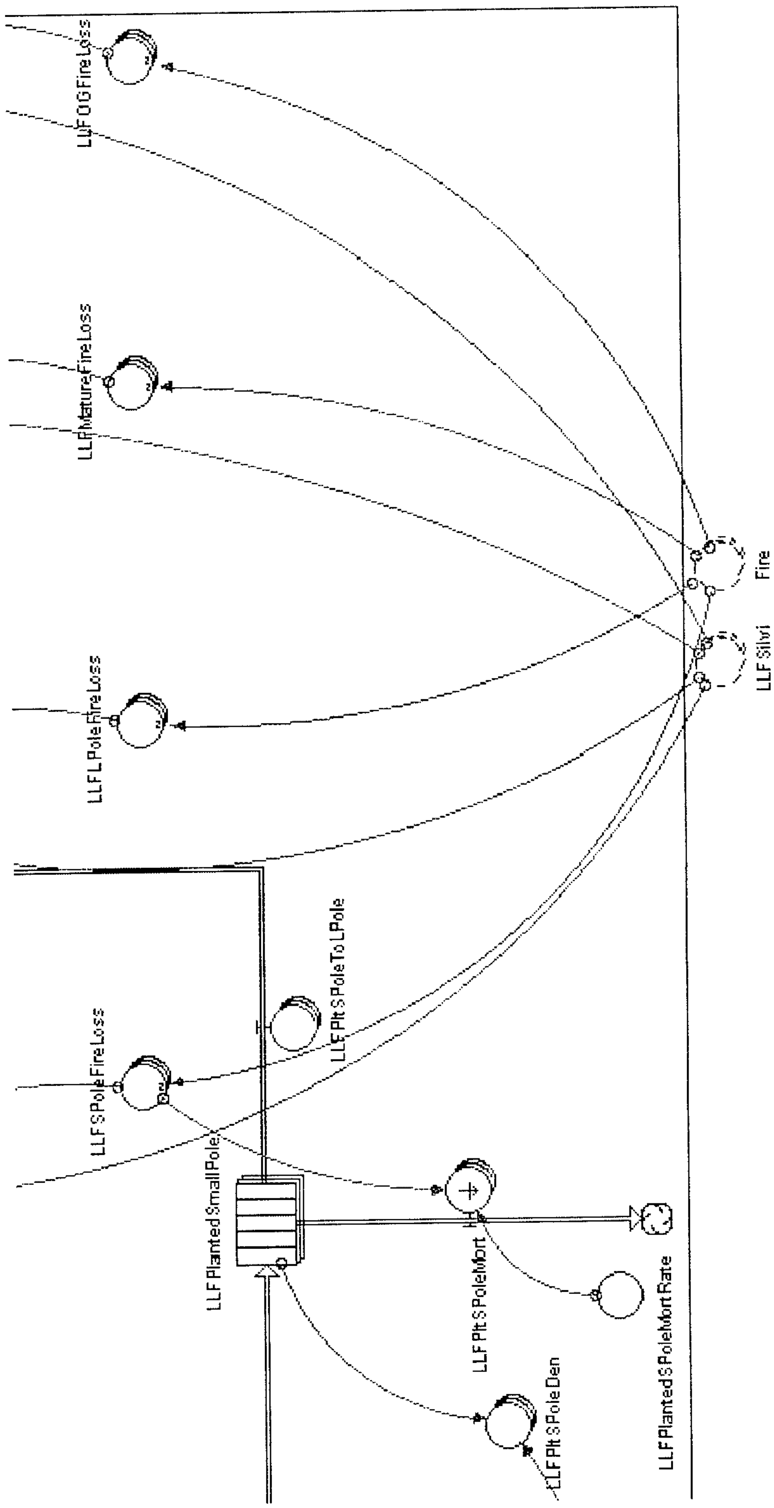

Figure 89: Flow Diagram: Longleaf Pine Sector (Part 4 of 4)

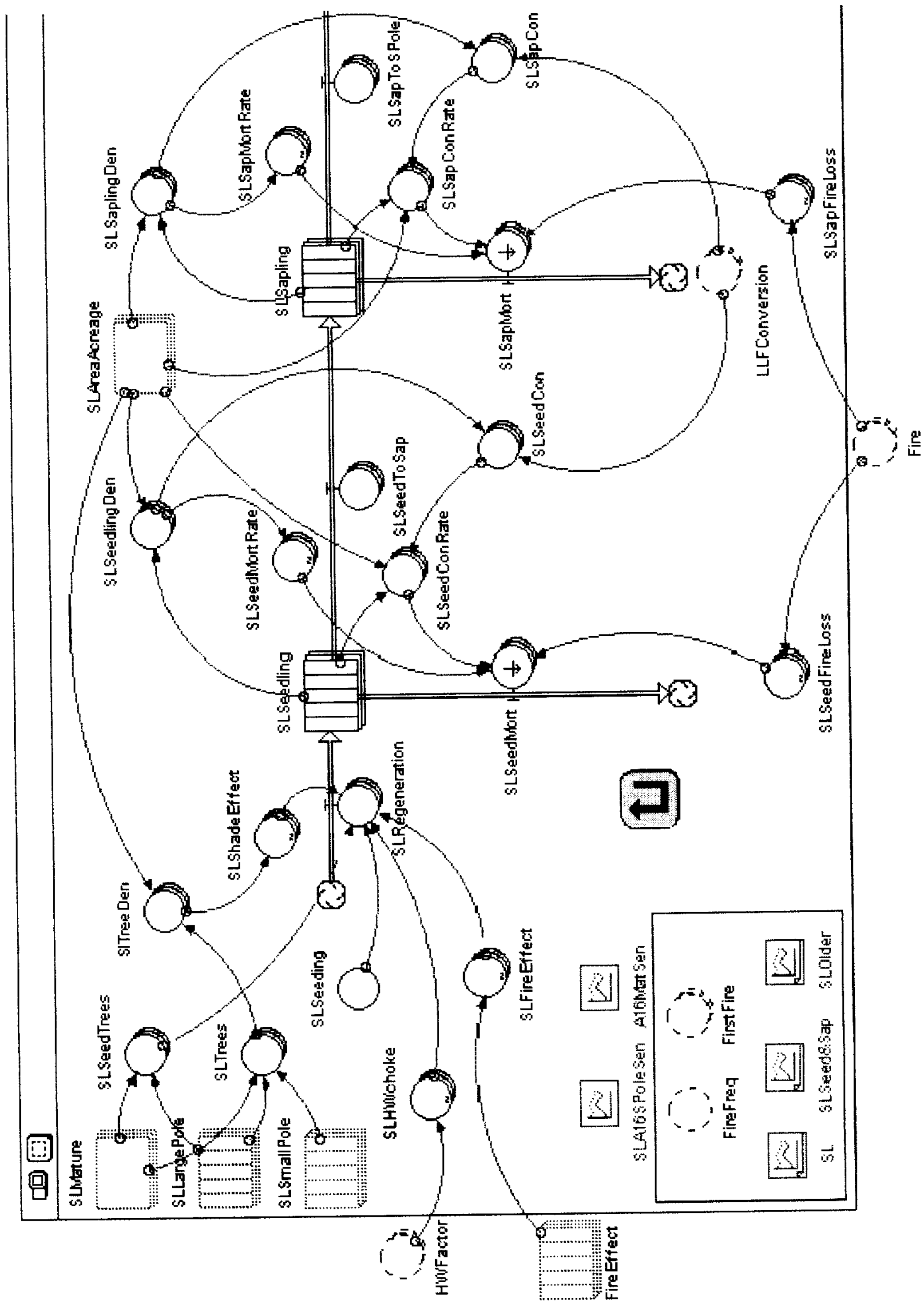

Figure 90: Flow Diagram: Slash Pine Sector (Part 1 of 2)

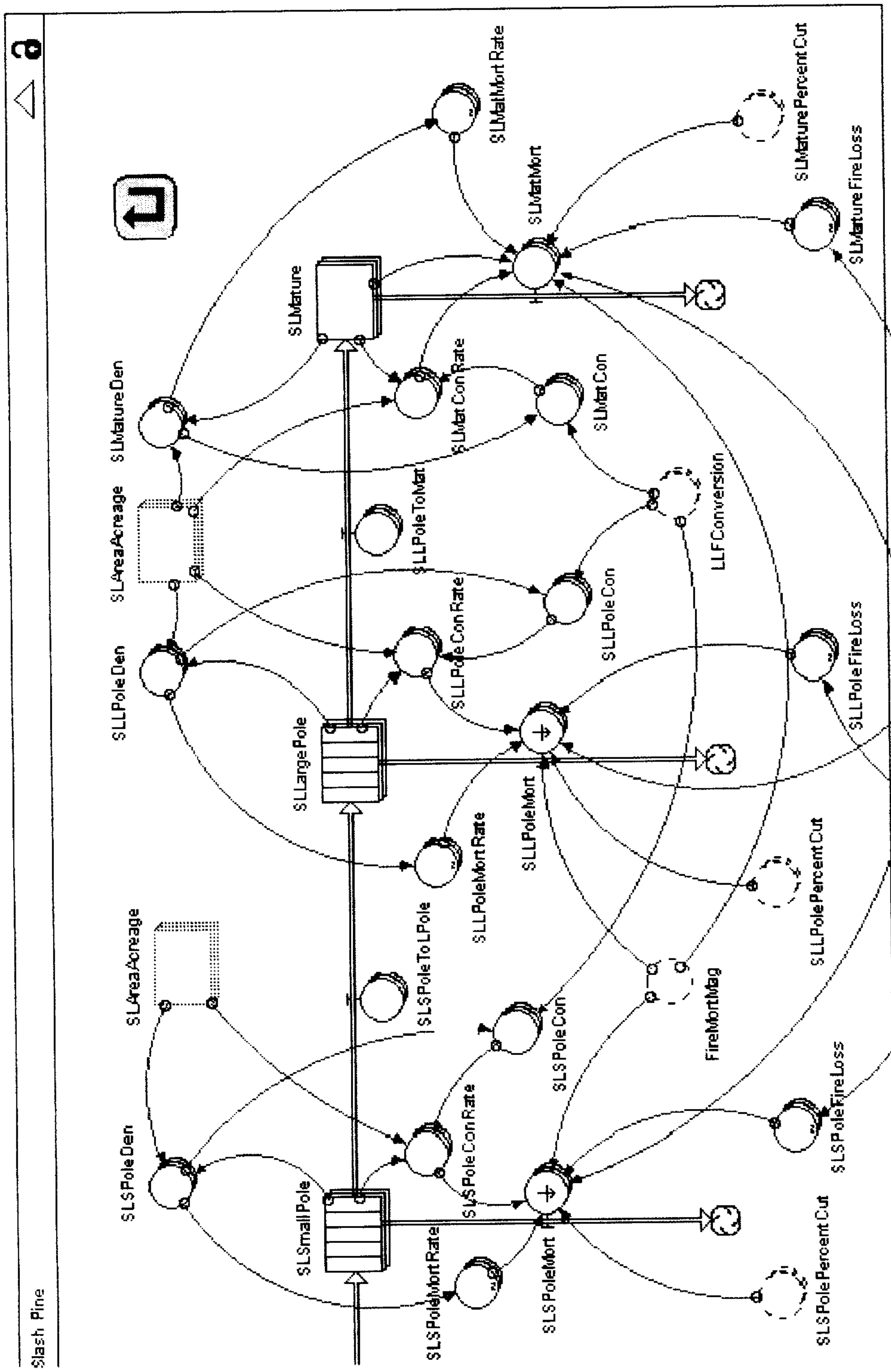

Figure 91: Flow Diagram: Slash Pine Sector (Part 2 of 2)

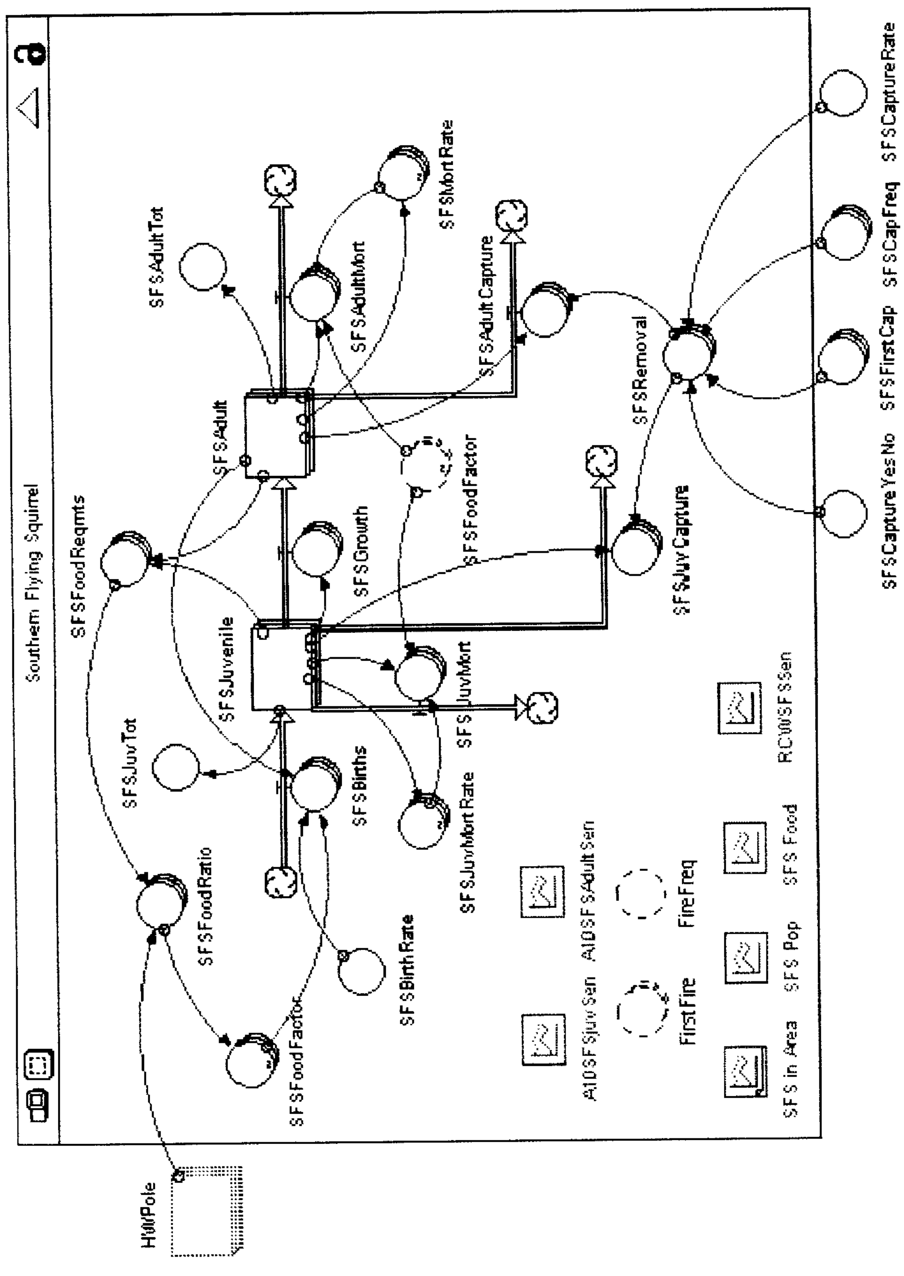

Figure 92: Flow Diagram: Southern Flying Squirrel Sector

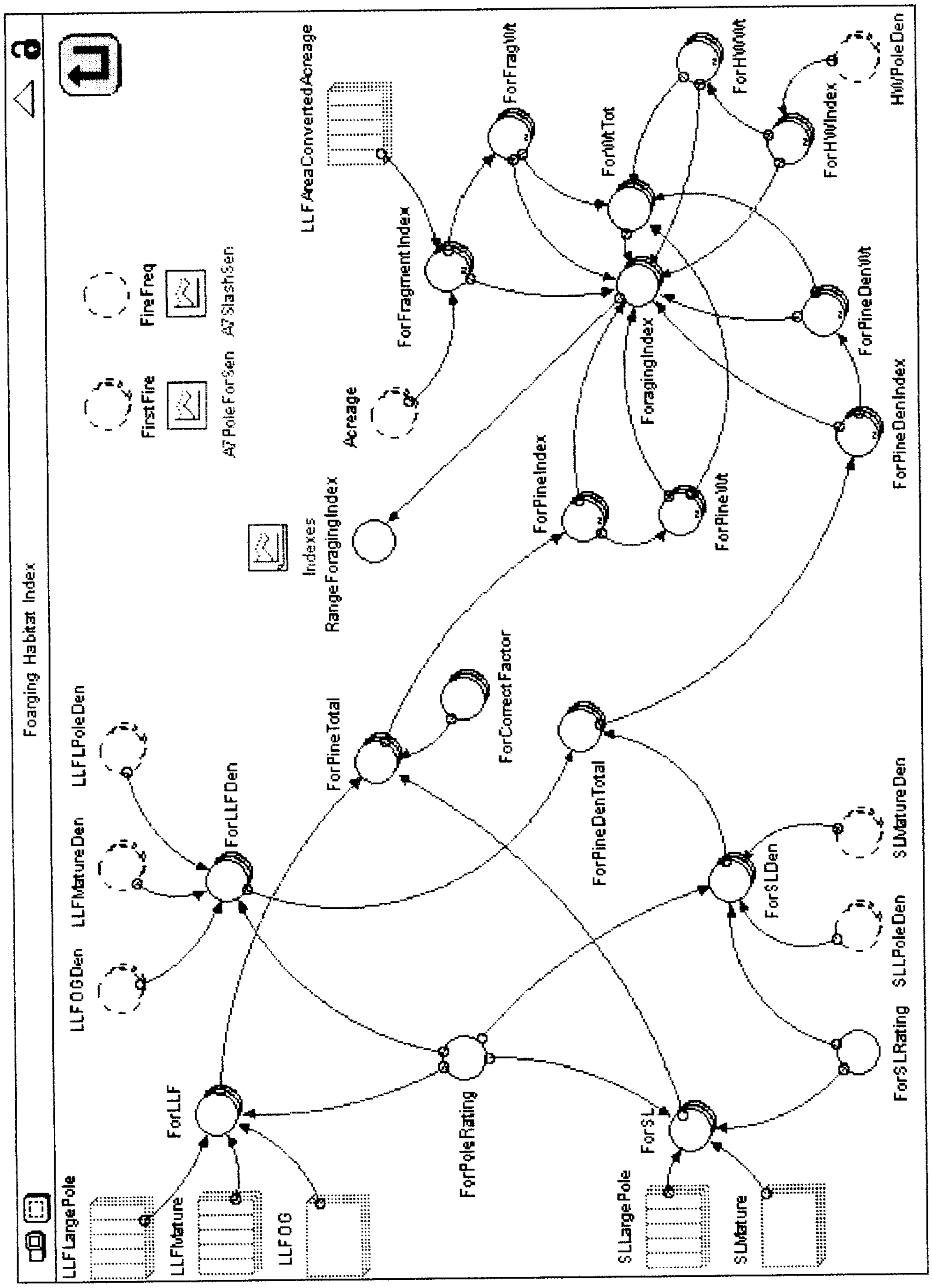

Figure 93: Flow Diagram: Foraging Habitat Index Sector

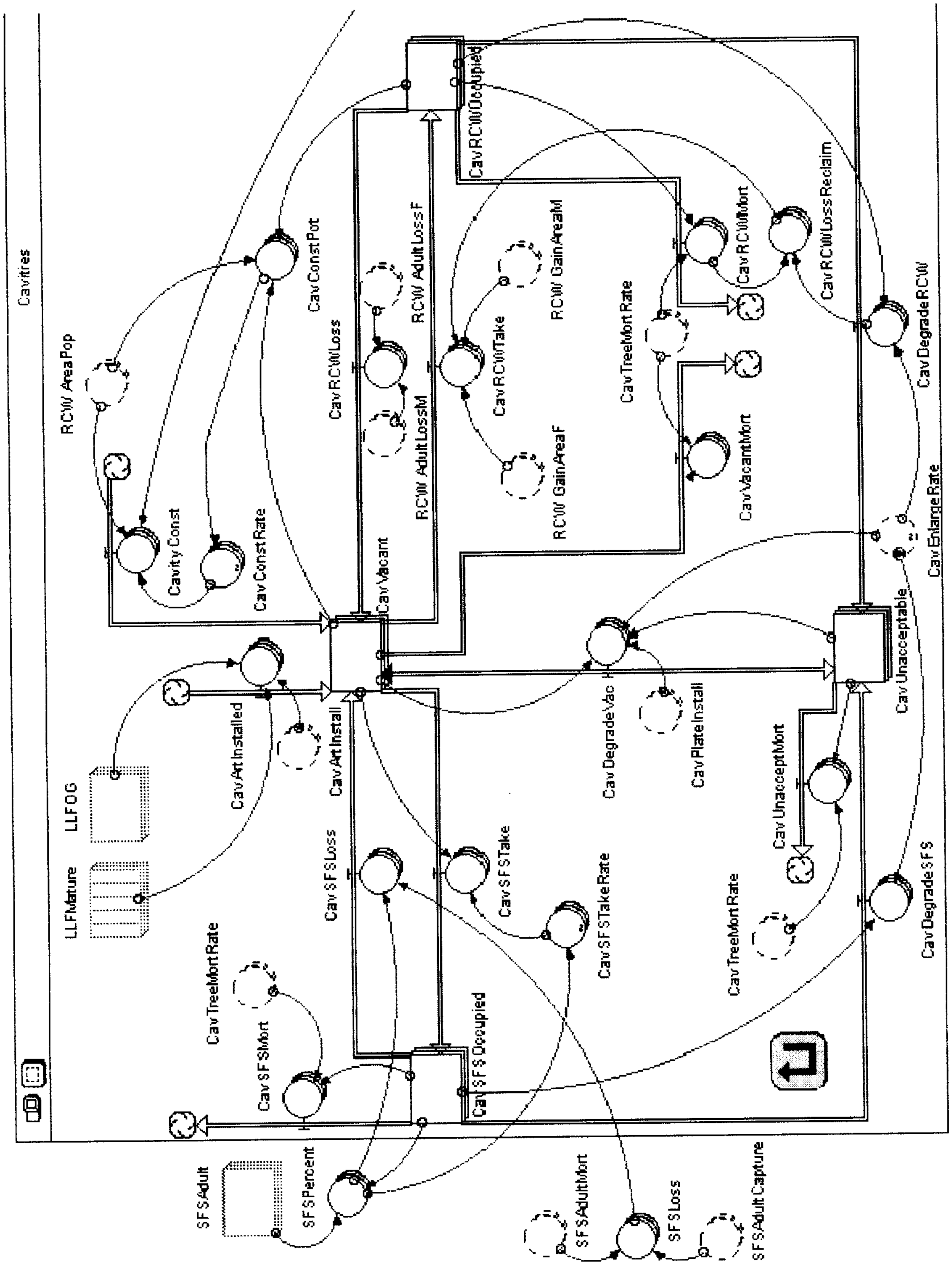

Figure 94: Flow Diagram: Cavities Sector (Part 1 of 2)

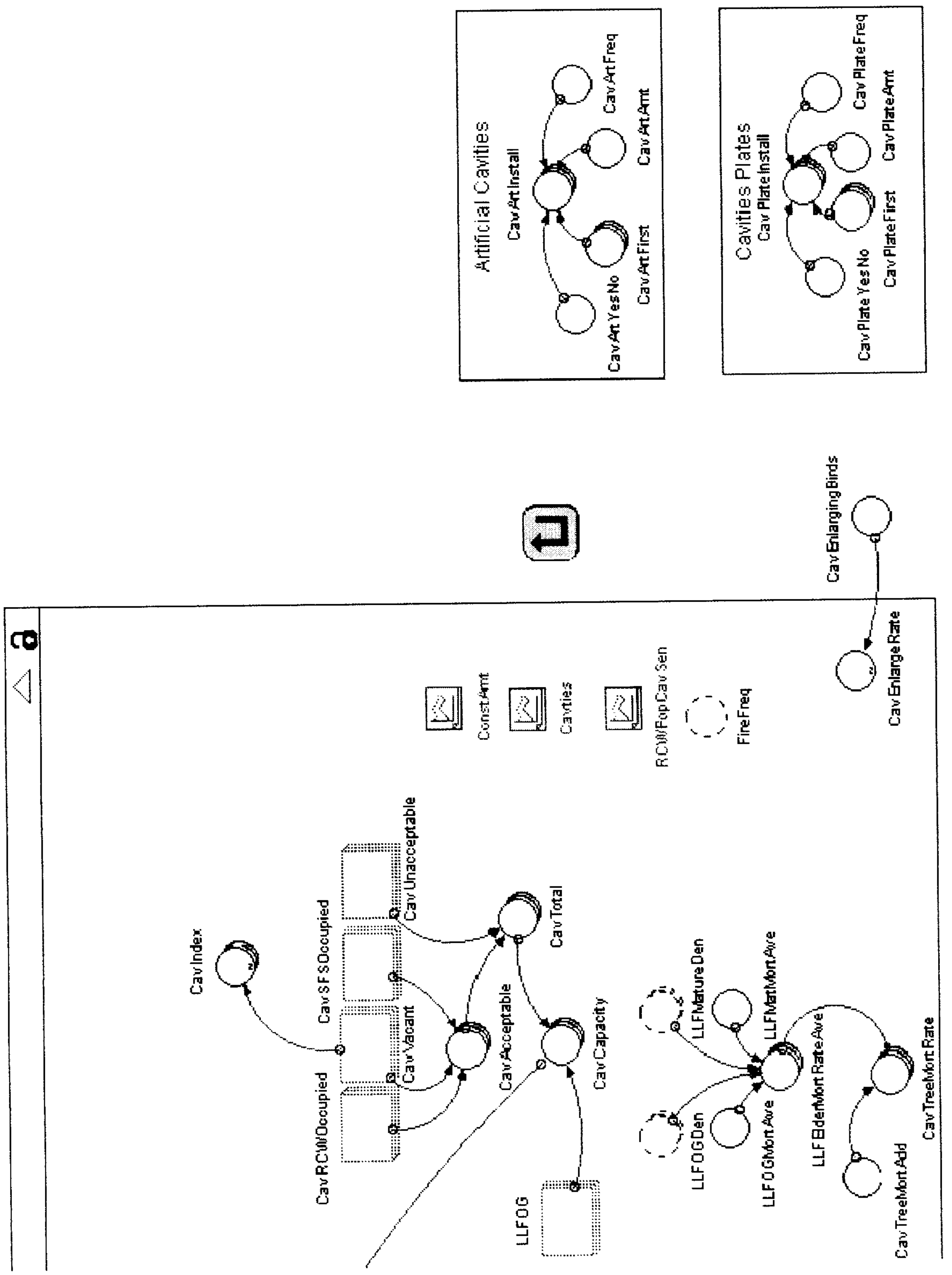

Figure 95: Flow Diagram: Cavities Sector (Part 2 of 2)

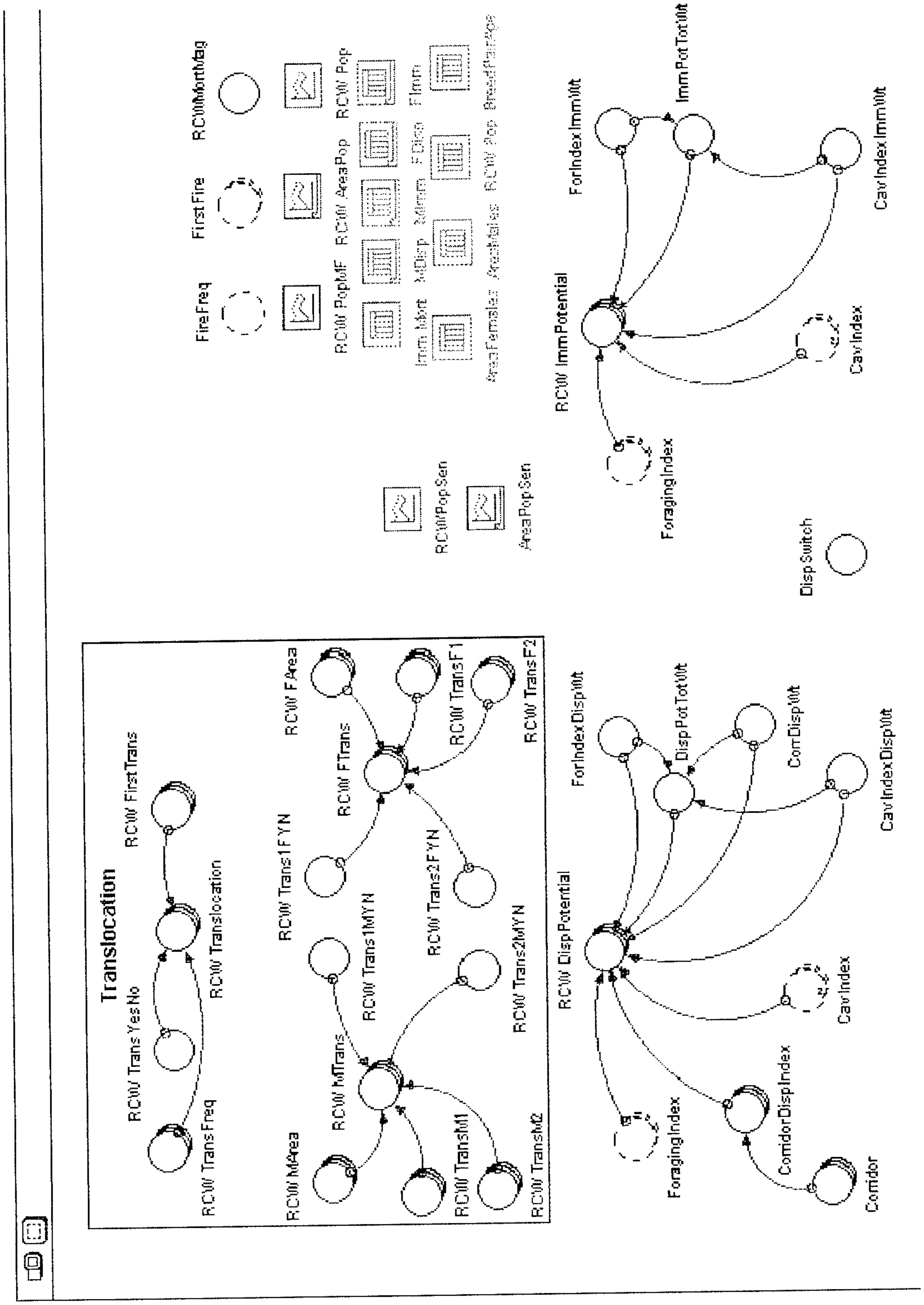

Figure 96: Flow Diagram: Red-Cockaded Woodpecker Sector (Part 1 of 6)

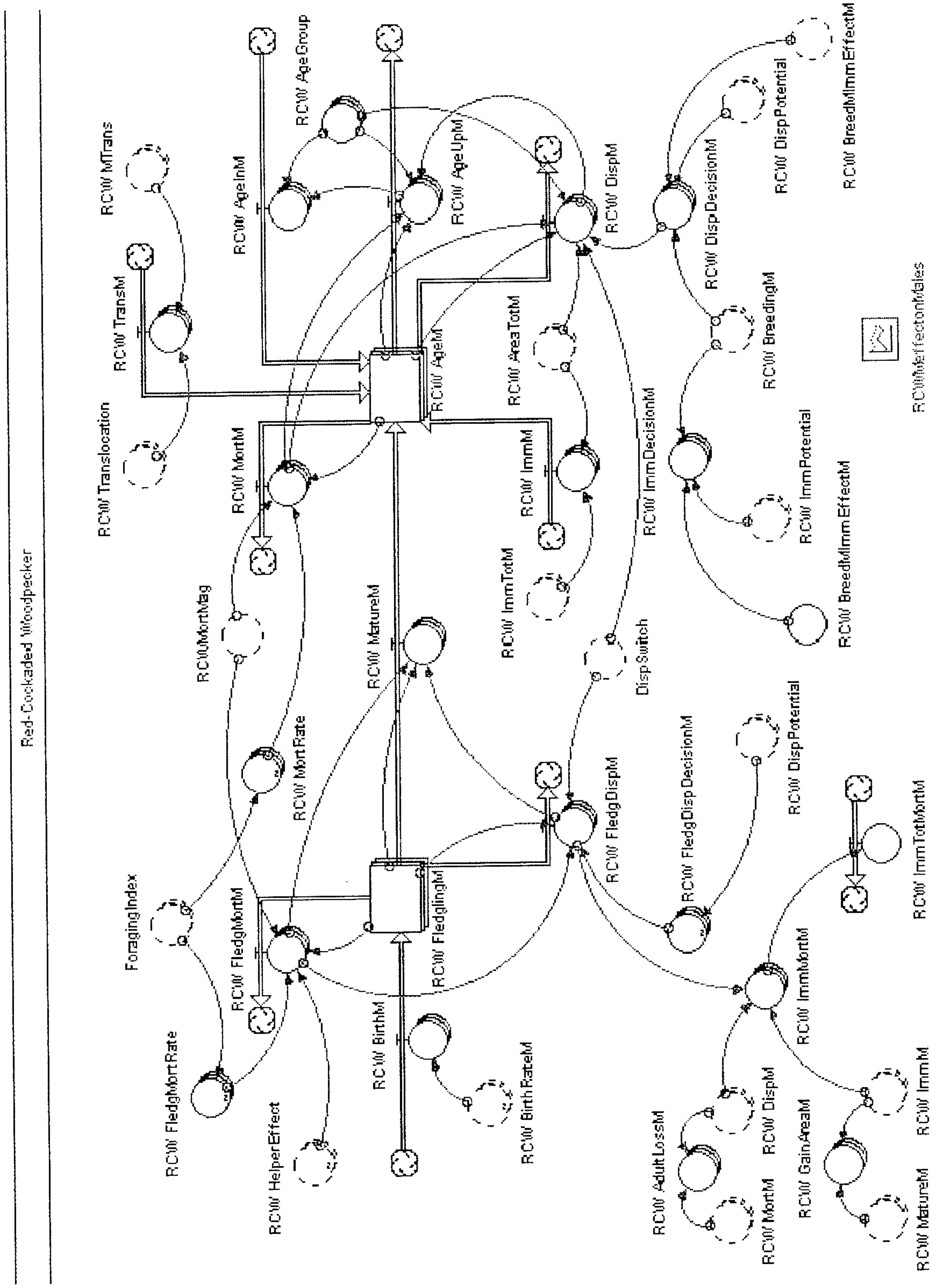

Figure 97: Flow Diagram: Red-Cockaded Woodpecker Sector (Part 2 of 6)

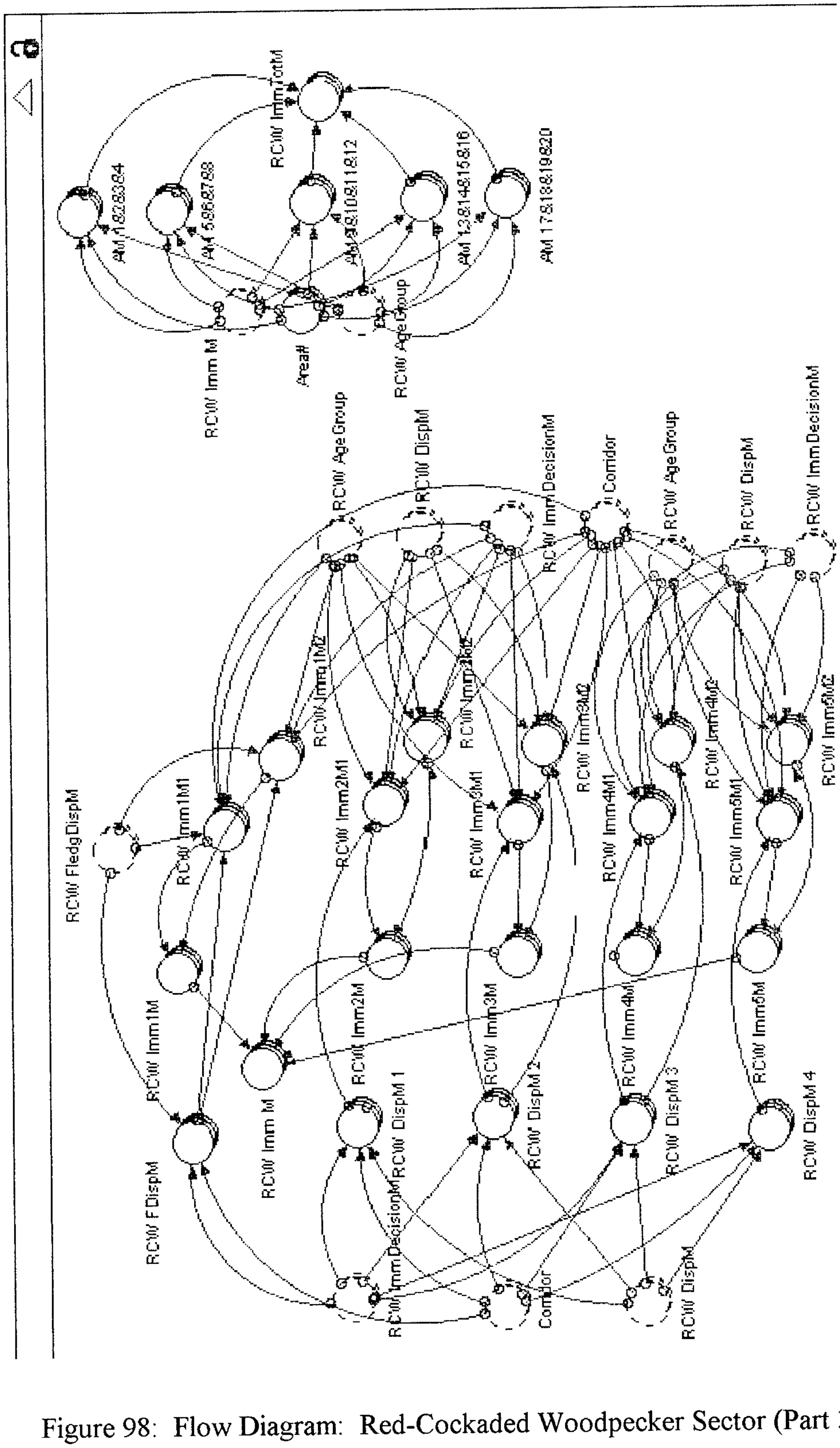

Figure 98: Flow Diagram: Red-Cockaded Woodpecker Sector (Part 3 of 6)

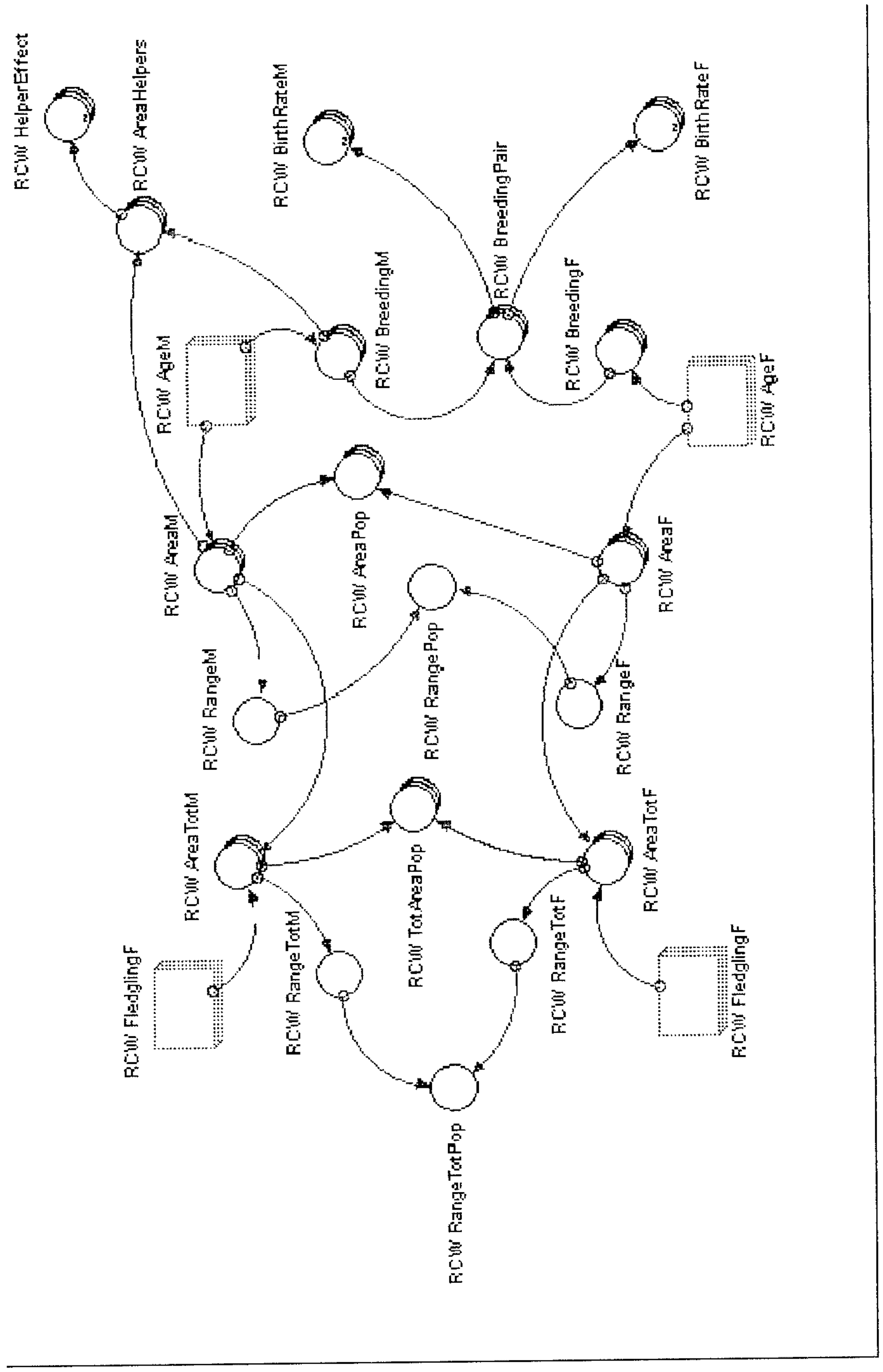

Figure 99: Flow Diagram: Red-Cockaded Woodpecker Sector (Part 4 of 6)

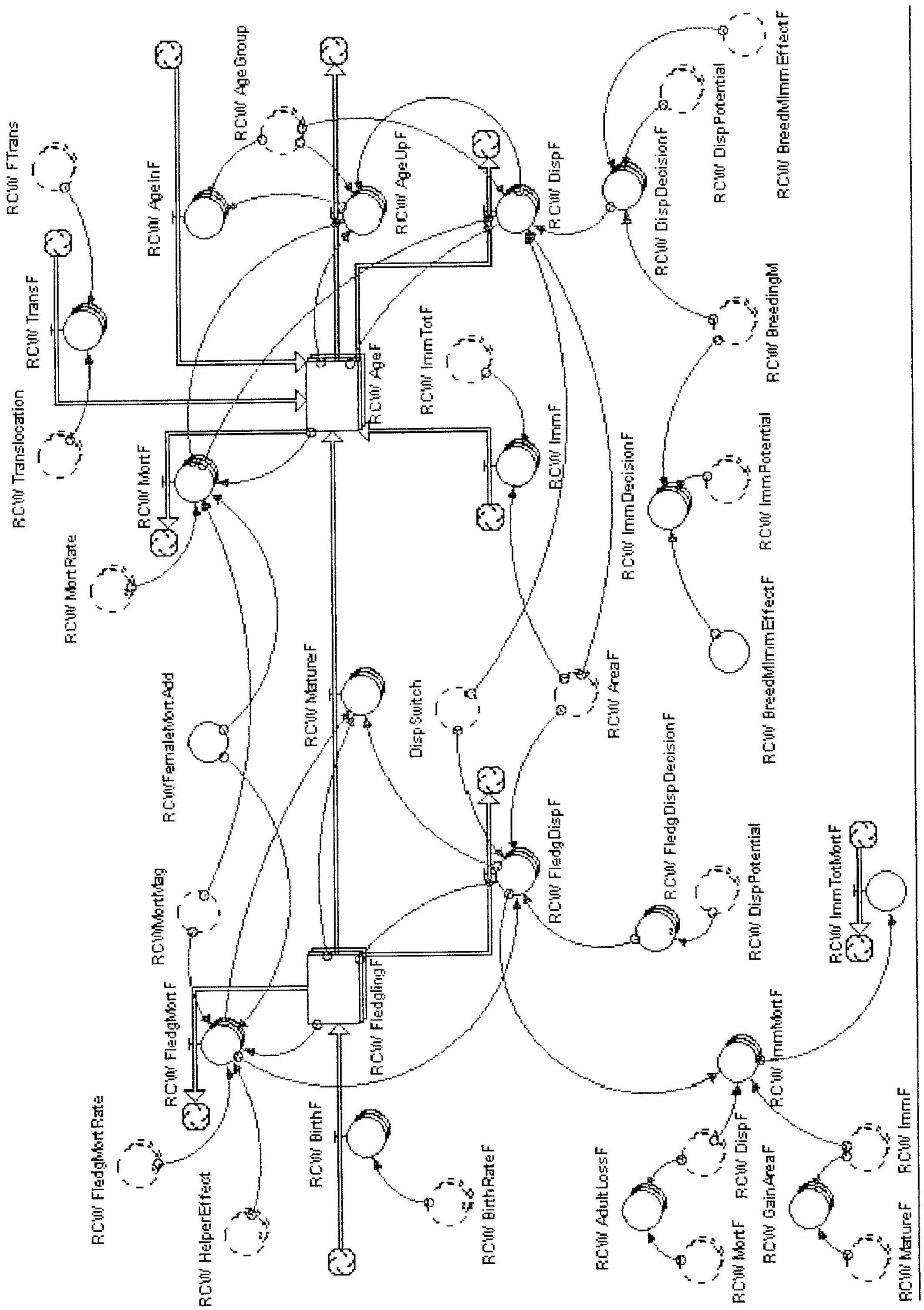

Figure 100: Flow Diagram: Red-Cockaded Woodpecker Sector (Part 5 of 6)

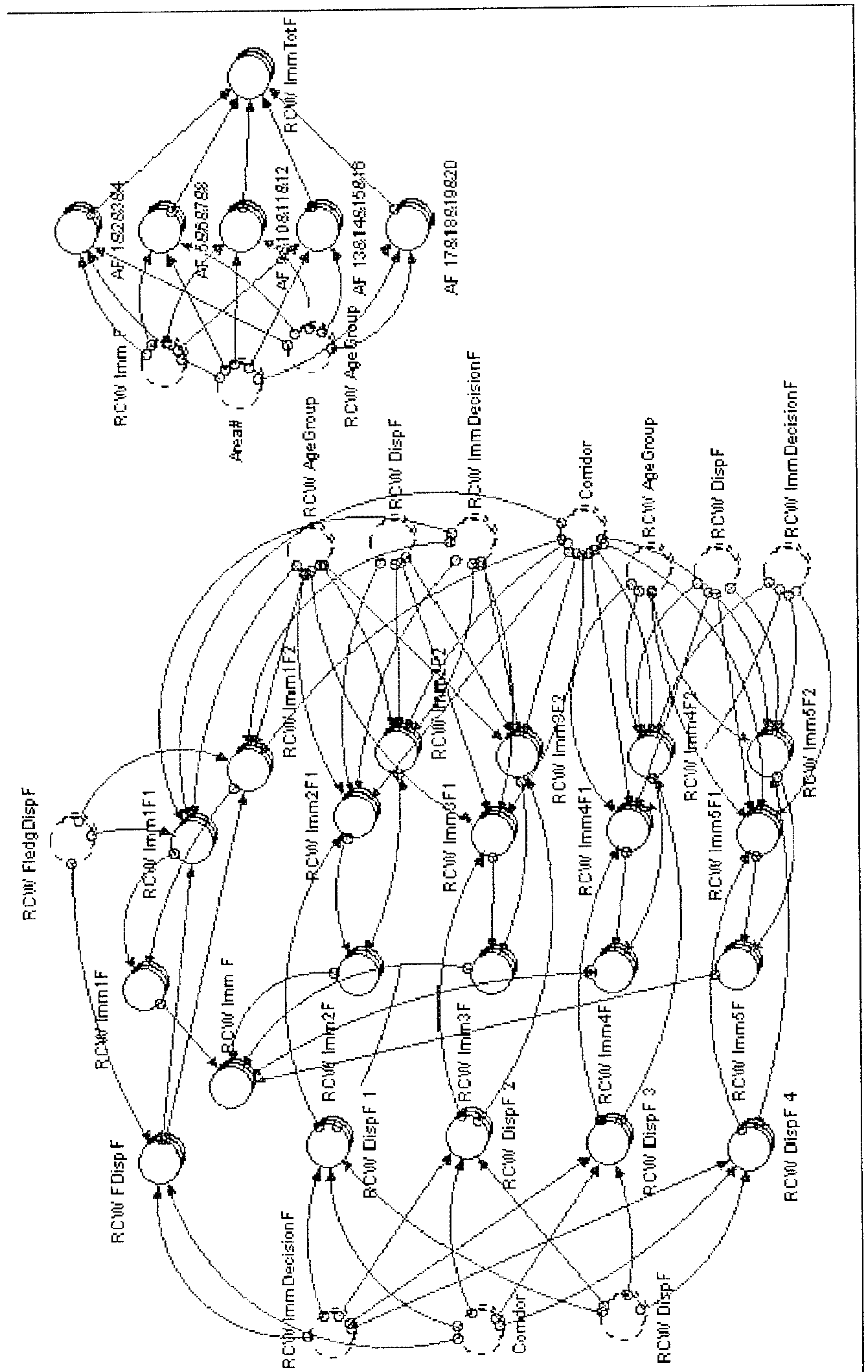

Figure 101: Flow Diagram: Red-Cockaded Woodpecker Sector (Part 6 of 6)

<u>Appendix C: Model Equations</u>

The STELLA equations used in the model are displayed for each sector alphabetically. Sector titles are boldfaced, underlined, and centered. "Inflows" and "Outflows" are boldfaced and underlined. "INIT" indicates the initial value of a stock. Format modifications were made to the equations for clarification purposes. Repetitious equations that were used in each of the twenty areas were consolidated into a single equation. When "**AREA**" or "**AGE**" is shown boldfaced in the equations, it signifies that the equation represents a consolidated equation. Initial input values and parameter values for arrayed variables, if different, are displayed grouped together for each arrayed variable. When possible, equations were arranged in columns.

==

<u>Acreage</u>

LLFAreaAcreage[**AREA**](t) = LLFAreaAcreage[**AREA**](t - dt) + (LLFConverted[**AREA**]) * dt

INIT LLFAreaAcreage[A1] = 180
INIT LLFAreaAcreage[A2] = 255
INIT LLFAreaAcreage[A3] = 240
INIT LLFAreaAcreage[A4] = 100
INIT LLFAreaAcreage[A5] = 230
INIT LLFAreaAcreage[A6] = 155
INIT LLFAreaAcreage[A7] = 45
INIT LLFAreaAcreage[A8] = 255
INIT LLFAreaAcreage[A9] = 195
INIT LLFAreaAcreage[A10] = 140
INIT LLFAreaAcreage[A11] = 75
INIT LLFAreaAcreage[A12] = 230
INIT LLFAreaAcreage[A13] = 215
INIT LLFAreaAcreage[A14] = 110
INIT LLFAreaAcreage[A15] = 150
INIT LLFAreaAcreage[A16] = 130
INIT LLFAreaAcreage[A17] = 155
INIT LLFAreaAcreage[A18] = 120
INIT LLFAreaAcreage[A19] = 180
INIT LLFAreaAcreage[A20] = 330

<u>INFLOWS</u>:

LLFConverted[Area] = CONVEYOR OUTFLOW

LLFAreaConvertedAcreage[A1](t) = LLFAreaConvertedAcreage[A1](t - dt) + (LLFConversion[A1] - LLFConverted[A1]) * dt

TRANSIT TIME = 28
INFLOW LIMIT = INF
CAPACITY = INF

INIT LLFAreaConvertedAcreage[A1] = 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,5,
INIT LLFAreaConvertedAcreage[A2] = 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
INIT LLFAreaConvertedAcreage[A3] = 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,10
INIT LLFAreaConvertedAcreage[A4] = 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0

INIT LLFAreaConvertedAcreage[A5] = 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,5,0
INIT LLFAreaConvertedAcreage[A6] = 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
INIT LLFAreaConvertedAcreage[A7] = 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,15
INIT LLFAreaConvertedAcreage[A8] = 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,20,0
INIT LLFAreaConvertedAcreage[A9] = 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
INIT LLFAreaConvertedAcreage[A10] = 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,10
INIT LLFAreaConvertedAcreage[A11] = 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
INIT LLFAreaConvertedAcreage[A12] = 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,20
INIT LLFAreaConvertedAcreage[A13] = 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
INIT LLFAreaConvertedAcreage[A14] = 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
INIT LLFAreaConvertedAcreage[A15] = 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
INIT LLFAreaConvertedAcreage[A16] = 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
INIT LLFAreaConvertedAcreage[A17] = 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,20
INIT LLFAreaConvertedAcreage[A18] = 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,45,0,30,0
INIT LLFAreaConvertedAcreage[A19] = 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,10,0
INIT LLFAreaConvertedAcreage[A20] = 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,30,0,15,0

INFLOWS:

LLFConversion[Area] = IF(SLAreaAcreage[Area]=0)THEN(0)ELSE(
ConvertYesNo[Area]*(IF(Area#[Area]=20)THEN(
PULSE((ConversionAcreage*ManchesterSwitch),FirstConvert[Area],ConversionFreq))
ELSE(PULSE(ConversionAcreage,FirstConvert[Area],ConversionFreq))))

OUTFLOWS:

LLFConverted[Area] = CONVEYOR OUTFLOW

SLAreaAcreage[**AREA**](t) = SLAreaAcreage[**AREA**](t - dt) - (LLFConversion[**AREA**]) * dt

INIT SLAreaAcreage[A1] = 155
INIT SLAreaAcreage[A2] = 25
INIT SLAreaAcreage[A3] = 5
INIT SLAreaAcreage[A4] = 150
INIT SLAreaAcreage[A5] = 10
INIT SLAreaAcreage[A6] = 85
INIT SLAreaAcreage[A7] = 215
INIT SLAreaAcreage[A8] = 0
INIT SLAreaAcreage[A9] = 0
INIT SLAreaAcreage[A10] = 110
INIT SLAreaAcreage[A11] = 240
INIT SLAreaAcreage[A12] = 75
INIT SLAreaAcreage[A13] = 120
INIT SLAreaAcreage[A14] = 195
INIT SLAreaAcreage[A15] = 175
INIT SLAreaAcreage[A16] = 220
INIT SLAreaAcreage[A17] = 40
INIT SLAreaAcreage[A18] = 130
INIT SLAreaAcreage[A19] = 240
INIT SLAreaAcreage[A20] = 140

OUTFLOWS:

LLFConversion[Area] = IF(SLAreaAcreage[Area]=0)THEN(0)ELSE(
ConvertYesNo[Area]*(IF(Area#[Area]=20)THEN(
PULSE((ConversionAcreage*ManchesterSwitch),FirstConvert[Area],ConversionFreq))
ELSE(PULSE(ConversionAcreage,FirstConvert[Area],ConversionFreq))))

Acreage[Area] = LLFAreaAcreage[Area]+LLFAreaConvertedAcreage[Area]+SLAreaAcreage[Area]

ConversionAcreage = 35

ConversionFreq = 10

ConvertYesNo[Area] = 0

FirstConvert[A1] = 0
FirstConvert[A2] = 2
FirstConvert[A3] = 4
FirstConvert[A4] = 6
FirstConvert[A5] = 8
FirstConvert[A6] = 0
FirstConvert[A7] = 2
FirstConvert[A8] = 4
FirstConvert[A9] = 6
FirstConvert[A10] = 8
FirstConvert[A11] = 0
FirstConvert[A12] = 2

FirstConvert[A13] = 4 FirstConvert[A15] = 8 FirstConvert[A17] = 2 FirstConvert[A19] = 6
FirstConvert[A14] = 6 FirstConvert[A16] = 0 FirstConvert[A18] = 4 FirstConvert[A20] = 8

LLFTotalAcreage = ARRAYSUM(LLFAreaAcreage[*])

LLFTotalConvertedAcreage = ARRAYSUM(LLFAreaConvertedAcreage[*])

ManchesterSwitch = IF(SLAreaAcreage[A20]<=90)THEN(0)ELSE(1)

SLTotalAcreage = ARRAYSUM(SLAreaAcreage[*])

TotalAcreage = ARRAYSUM(Acreage[*])

Cavities

CavRCWOccupied[Area](t) = CavRCWOccupied[Area](t - dt) + (CavRCWTake[Area] - CavDegradeRCW[Area] - CavRCWLoss[Area] - CavRCWMort[Area]) * dt

INIT CavRCWOccupied[Area] = RCW_AreaPop[Area]

INFLOWS:

CavRCWTake[Area] = ROUND(RCW_GainAreaF[Area]+RCW_GainAreaM[Area])+CavRCWLossReclaim[Area]

OUTFLOWS:

CavDegradeRCW[Area] = ROUND(CavRCWOccupied[Area]*CavEnlargeRate)

CavRCWLoss[Area] = ROUND(RCW_AdultLossF[Area]+RCW_AdultLossM[Area])

CavRCWMort[Area] = ROUND(CavRCWOccupied[Area]*CavTreeMortRate[Area])

CavSFSOccupied[**AREA**](t) = CavSFSOccupied[**AREA**](t - dt) + (CavSFSTake[**AREA**] - CavSFSMort[**AREA**] - CavDegradeSFS[**AREA**] - CavSFSLoss[**AREA**]) * dt

INIT CavSFSOccupied[A1] = 0
INIT CavSFSOccupied[A2] = 1
INIT CavSFSOccupied[A3] = 0
INIT CavSFSOccupied[A4] = 0
INIT CavSFSOccupied[A5] = 2
INIT CavSFSOccupied[A6] = 0
INIT CavSFSOccupied[A7] = 0
INIT CavSFSOccupied[A8] = 0
INIT CavSFSOccupied[A9] = 2
INIT CavSFSOccupied[A10] = 0
INIT CavSFSOccupied[A11] = 2
INIT CavSFSOccupied[A12] = 0
INIT CavSFSOccupied[A13] = 3
INIT CavSFSOccupied[A14] = 0
INIT CavSFSOccupied[A15] = 1
INIT CavSFSOccupied[A16] = 0
INIT CavSFSOccupied[A17] = 1
INIT CavSFSOccupied[A18] = 1
INIT CavSFSOccupied[A19] = 0
INIT CavSFSOccupied[A20] = 0

INFLOWS:

CavSFSTake[Area] = Round(CavVacant[Area]*CavSFSTakeRate[Area])

OUTFLOWS:

CavSFSMort[Area] = ROUND(CavSFSOccupied[Area]*CavTreeMortRate[Area])

CavDegradeSFS[Area] = ROUND(CavSFSOccupied[Area]*CavEnlargeRate)

CavSFSLoss[Area] = ROUND(SFSLoss[Area]*SFSPercent[Area])

CavUnacceptable[**AREA**](t) = CavUnacceptable[**AREA**](t - dt) + (CavDegradeVac[**AREA**] + CavDegradeRCW[**AREA**] + CavDegradeSFS[**AREA**] - CavUnacceptMort[**AREA**]) * dt

INIT CavUnacceptable[A1] = 0
INIT CavUnacceptable[A2] = 0
INIT CavUnacceptable[A3] = 0
INIT CavUnacceptable[A4] = 0
INIT CavUnacceptable[A5] = 1
INIT CavUnacceptable[A6] = 1
INIT CavUnacceptable[A7] = 0
INIT CavUnacceptable[A8] = 2
INIT CavUnacceptable[A9] = 2
INIT CavUnacceptable[A10] = 0
INIT CavUnacceptable[A11] = 0
INIT CavUnacceptable[A12] = 2
INIT CavUnacceptable[A13] = 2
INIT CavUnacceptable[A14] = 0
INIT CavUnacceptable[A15] = 2
INIT CavUnacceptable[A16] = 0
INIT CavUnacceptable[A17] = 2
INIT CavUnacceptable[A18] = 4
INIT CavUnacceptable[A19] = 0
INIT CavUnacceptable[A20] = 9

INFLOWS:

CavDegradeVac[Area] = ROUND(CavVacant[Area]*CavEnlargeRate-(IF(CavPlateInstall[Area]>0)THEN(IF(CavPlateInstall[Area]>CavUnacceptable[Area])THEN (CavUnacceptable[Area])ELSE(CavUnacceptable[Area]-CavPlateInstall[Area]))ELSE(0)))

CavDegradeRCW[Area] = ROUND(CavRCWOccupied[Area]*CavEnlargeRate)

CavDegradeSFS[Area] = ROUND(CavSFSOccupied[Area]*CavEnlargeRate)

OUTFLOWS:

CavUnacceptMort[Area] = ROUND(CavUnacceptable[Area]*CavTreeMortRate[Area])

CavVacant[**AREA**](t) = CavVacant[**AREA**](t - dt) + (CavArtInstalled[**AREA**] + CavRCWLoss[**AREA**] + CavSFSLoss[**AREA**] + CavityConst[**AREA**] - CavDegradeVac[**AREA**] - CavVacantMort[**AREA**] - CavRCWTake[**AREA**] - CavSFSTake[**AREA**]) * dt

INIT CavVacant[A1] = 1
INIT CavVacant[A2] = 0
INIT CavVacant[A3] = 0
INIT CavVacant[A4] = 3
INIT CavVacant[A5] = 2
INIT CavVacant[A6] = 3
INIT CavVacant[A7] = 0
INIT CavVacant[A8] = 7
INIT CavVacant[A9] = 6
INIT CavVacant[A10] = 0
INIT CavVacant[A11] = 0
INIT CavVacant[A12] = 6
INIT CavVacant[A13] = 8
INIT CavVacant[A14] = 0
INIT CavVacant[A15] = 6
INIT CavVacant[A16] = 1
INIT CavVacant[A17] = 4
INIT CavVacant[A18] = 10
INIT CavVacant[A19] = 1
INIT CavVacant[A20] = 18

INFLOWS:

CavArtInstalled[Area] = IF(LLFOG[Area]+LLFMature[Area]>5)THEN(CavArtInstall[Area])ELSE(0)

CavRCWLoss[Area] = ROUND(RCW_AdultLossF[Area]+RCW_AdultLossM[Area])

CavSFSLoss[Area] = ROUND(SFSLoss[Area]*SFSPercent[Area])

CavityConst[Area] = ROUND(RCW_AreaPop[Area]*CavConstRate[Area]*(1-CavCapacity[Area]))

OUTFLOWS:

CavDegradeVac[Area] = ROUND(CavVacant[Area]*CavEnlargeRate-(IF(CavPlateInstall[Area]>0)THEN(IF(CavPlateInstall[Area]>CavUnacceptable[Area])THEN (CavUnacceptable[Area])ELSE(CavUnacceptable[Area]-CavPlateInstall[Area]))ELSE(0)))

CavVacantMort[Area] = ROUND(CavVacant[Area]*CavTreeMortRate[Area])

CavRCWTake[Area] =
ROUND(RCW_GainAreaF[Area]+RCW_GainAreaM[Area])+CavRCWLossReclaim[Area]

CavSFSTake[Area] = Round(CavVacant[Area]*CavSFSTakeRate[Area])

CavAcceptable[Area] = CavRCWOccupied[Area]+CavSFSOccupied[Area]+CavVacant[Area]

CavCapacity[Area] = IF(LLFOG[Area]=0)THEN(0)ELSE(CavTotal[Area]/LLFOG[Area])

CavConstPot[Area] = IF((CavVacant[Area]+CavRCWOccupied[Area])>0)THEN(RCW_AreaPop[Area]/(CavRCWOccupied[Area]+CavVacant[Area]))ELSE(0)

CavRCWLossReclaim[Area] = CavDegradeRCW[Area]+CavRCWMort[Area]

CavTotal[Area] = CavUnacceptable[Area]+CavAcceptable[Area]

CavTreeMortAdd = 0.04

CavTreeMortRate[Area] = LLFElderMortRateAve[Area]+CavTreeMortAdd

LLFElderMortRateAve[Area] =
IF(LLFMatureDen[Area]=0)OR(LLFOGDen[Area]=0)THEN(0.0175)ELSE((LLFMatMortAve*
LLFMatureDen[Area]+LLFOGMortAve*LLFOGDen[Area])/(LLFMatureDen[Area]+LLFOGDen[Area]))

LLFMatMortAve = 0.02

LLFOGMortAve = 0.014

CavConstRate[Area] = GRAPH(CavConstPot[Area])

(0.00, 0.25), (0.1, 0.25), (0.2, 0.26), (0.3, 0.279), (0.4, 0.306), (0.5, 0.344), (0.6, 0.384), (0.7, 0.429), (0.8, 0.461), (0.9, 0.494), (1, 0.5)

CavEnlargeRate = GRAPH(CavEnlargingBirds)

(0.00, 0.03), (2.00, 0.0405), (4.00, 0.0525), (6.00, 0.063), (8.00, 0.0715), (10.0, 0.079), (12.0, 0.087), (14.0, 0.0925), (16.0, 0.0965), (18.0, 0.099), (20.0, 0.1)

CavIndex[Area] = GRAPH(CavVacant[Area])

(0.00, 0.00), (1.50, 0.035), (3.00, 0.105), (4.50, 0.23), (6.00, 0.405), (7.50, 0.56), (9.00, 0.755), (10.5, 0.88), (12.0, 0.945), (13.5, 0.995), (15.0, 1.00)

CavSFSTakeRate[Area] = GRAPH(SFSPercent[Area])

(0.00, 0.00), (0.05, 0.187), (0.1, 0.31), (0.15, 0.404), (0.2, 0.48), (0.25, 0.544), (0.3, 0.584), (0.35, 0.614), (0.4, 0.634), (0.45, 0.654), (0.5, 0.667)

Fire

FireEffect[Area](t) = FireEffect[Area](t - dt) + (FireInput[Area] - FireThru[Area] - FireDrain[Area]) * dt

INIT FireEffect[Area] = 0

INFLOWS:

FireInput[Area] = FireFactor[Area]

OUTFLOWS:

FireThru[Area] = CONVEYOR OUTFLOW
FireDrain[Area] = LEAKAGE OUTFLOW

LEAKAGE FRACTION = 0.75
NO-LEAK ZONE = 0

FireIntensity[Area](t) = FireIntensity[Area](t - dt) + (FireIntenBuild[Area] - FireIntenLoss[Area]) * dt

INIT FireIntensity[Area] = 0

INFLOWS:

FireIntenBuild[Area] = IF(FireIntensity[Area]<1)THEN(FireIntenRate*FireIntenFraction[Area])ELSE(0)

OUTFLOWS:

FireIntenLoss[Area] = FireIntensity[Area]*FireFactor[Area]

Fire[Area] =
IF(WildfireFactor[Area]=0)THEN(PULSE(FireIntensity[Area],FirstFire[Area],FireFreq))ELSE
(WildfireFactor[Area])

FireFactor[Area] = IF(Fire[Area]>0)Then(1)ELSE(0)

FireIntenFraction[Area] = TreeDensity[Area]/175

FireIntenRate = 1/15

HWDen[Area] = HWSapDen[Area]*0.01+HWPoleDen[Area]*0.25

LLFAmt[Area] = LLFAreaAcreage[Area]/(LLFAreaAcreage[Area]+SLAreaAcreage[Area])

LLFDen[Area] =
LLFSaplingDen[Area]*0.05+LLFSPoleDen[Area]*0.25+LLFLPoleDen[Area]*0.5+LLFMatureDen[Area]
*0.75+LLFOGDen[Area]

SLAmt[Area] = SLAreaAcreage[Area]/(LLFAreaAcreage[Area]+SLAreaAcreage[Area])

SLDen[Area] =
SLSaplingDen[Area]*0.05+SLSPoleDen[Area]*0.25+SLLPoleDen[Area]*0.5+SLMatureDen[Area]*0.75

TreeDensity[Area] = HWDen[Area]+LLFDen[Area]*LLFAmt[Area]+SLDen[Area]*SLAmt[Area]

WildfireFactor[Area] = PULSE(WildfireIntensity[Area],WhenWildfire[Area],500)

Foarging Habitat Index

ForagingIndex[Area] =
((ForFragmentIndex[Area]*ForFragWt[Area])+(ForHWIndex[Area]*ForHWWt[Area])+
(ForPineDenIndex[Area]*ForPineDenWt[Area])+(ForPineIndex[Area]*ForPineWt[Area]))/ForWtTot[Area]

ForCorrectFactor[A1] = 0	ForCorrectFactor[A8] = 0	ForCorrectFactor[A15] = 0
ForCorrectFactor[A2] = 0	ForCorrectFactor[A9] = 12750	ForCorrectFactor[A16] = 0
ForCorrectFactor[A3] = 0	ForCorrectFactor[A10] = 0	ForCorrectFactor[A17] = 14000
ForCorrectFactor[A4] = 0	ForCorrectFactor[A11] = 0	ForCorrectFactor[A18] = 0
ForCorrectFactor[A5] = 0	ForCorrectFactor[A12] = 0	ForCorrectFactor[A19] = 0
ForCorrectFactor[A6] = 0	ForCorrectFactor[A13] = 0	ForCorrectFactor[A20] = 19000
ForCorrectFactor[A7] = 0	ForCorrectFactor[A14] = 0	

ForLLF[Area] = LLFLargePole[Area]*ForPoleRating+LLFMature[Area]+LLFOG[Area]

ForLLFDen[Area] = LLFOGDen[Area]+LLFMatureDen[Area]+LLFLPoleDen[Area]*ForPoleRating

ForPineDenTotal[Area] = ForLLFDen[Area]+ForSLDen[Area]

ForPineTotal[Area] = ForLLF[Area]+ForSL[Area]+ForCorrectFactor[Area]

ForPoleRating = 0.6

ForSL[Area] = (SLLargePole[Area]*ForPoleRating+SLMature[Area])*ForSLRating
ForSLDen[Area] = (SLMatureDen[Area]+SLLPoleDen[Area]*ForPoleRating)*ForSLRating

ForSLRating = 0.5

ForWtTot[Area] = ForFragWt[Area]+ForHWWt[Area]+ForPineDenWt[Area]+ForPineWt[Area]

RangeForagingIndex = ARRAYMEAN(ForagingIndex[*])

ForFragmentIndex[Area] = GRAPH(LLFAreaConvertedAcreage[Area]/Acreage[Area])

(0.00, 1.00), (0.03, 0.68), (0.06, 0.485), (0.09, 0.355), (0.12, 0.245), (0.15, 0.185), (0.18, 0.12), (0.21, 0.08), (0.24, 0.05), (0.27, 0.02), (0.3, 0.00)

ForFragWt[Area] = GRAPH(ForFragmentIndex[Area])

(0.00, 15.0), (0.075, 14.7), (0.15, 14.2), (0.225, 13.4), (0.3, 12.6), (0.375, 11.6), (0.45, 10.5), (0.525, 8.63), (0.6, 5.25), (0.675, 3.04), (0.75, 2.00)

ForHWIndex[Area] = GRAPH(HWPoleDen[Area])

(0.00, 1.00), (4.50, 0.915), (9.00, 0.84), (13.5, 0.705), (18.0, 0.52), (22.5, 0.29), (27.0, 0.145), (31.5, 0.1), (36.0, 0.055), (40.5, 0.02), (45.0, 0.00)

ForHWWt[Area] = GRAPH(ForHWIndex[Area])

(0.00, 15.0), (0.05, 11.5), (0.1, 8.70), (0.15, 6.55), (0.2, 5.12), (0.25, 4.08), (0.3, 3.43), (0.35, 2.91), (0.4, 2.59), (0.45, 2.33), (0.5, 2.06)

ForPineDenIndex[Area] = GRAPH(ForPineDenTotal[Area])

(0.00, 0.005), (17.5, 0.125), (35.0, 0.47), (52.5, 0.64), (70.0, 0.745), (87.5, 0.81), (105, 0.845), (123, 0.885), (140, 0.93), (158, 0.96), (175, 1.00)

ForPineDenWt[Area] = GRAPH(ForPineDenIndex[Area])

(0.00, 14.9), (0.04, 10.7), (0.08, 7.93), (0.12, 5.97), (0.16, 4.57), (0.2, 3.45), (0.24, 2.47), (0.28, 1.77), (0.32, 1.35), (0.36, 1.14), (0.4, 1.00)

ForPineIndex[Area] = GRAPH(ForPineTotal[Area])

(0.00, 0.00), (4250, 0.035), (8500, 0.09), (12750, 0.17), (17000, 0.24), (21250, 0.4), (25500, 0.555), (29750, 0.755), (34000, 0.905), (38250, 0.965), (42500, 1.00)

ForPineWt[Area] = GRAPH(ForPineIndex[Area])

(0.00, 15.0), (0.04, 10.9), (0.08, 7.53), (0.12, 5.58), (0.16, 4.47), (0.2, 3.69), (0.24, 3.11), (0.28, 2.65), (0.32, 2.46), (0.36, 2.19), (0.4, 2.06)

Hardwood

HWPole[**AREA**](t) = HWPole[**AREA**](t - dt) + (HWSapToPole[**AREA**] - HWPoleMort[**AREA**] - HWHerbPoleLoss[**AREA**] - HWSilviLoss[**AREA**]) * dt

INIT HWPole[A1] = 6000
INIT HWPole[A2] = 4800
INIT HWPole[A3] = 0
INIT HWPole[A4] = 700
INIT HWPole[A5] = 5100
INIT HWPole[A6] = 20
INIT HWPole[A7] = 5800
INIT HWPole[A8] = 600
INIT HWPole[A9] = 2200
INIT HWPole[A10] = 5600
INIT HWPole[A11] = 4700
INIT HWPole[A12] = 200
INIT HWPole[A13] = 3000
INIT HWPole[A14] = 2300
INIT HWPole[A15] = 1200
INIT HWPole[A16] = 3800
INIT HWPole[A17] = 900
INIT HWPole[A18] = 400
INIT HWPole[A19] = 2100
INIT HWPole[A20] = 0

INFLOWS:

HWSapToPole[Area] = CONVEYOR OUTFLOW

OUTFLOWS:

HWPoleMort[Area] = HWPole[Area]*HWPoleMortRate[Area]+HWPole[Area]*HWPoleFireLoss[Area]*(1-HWResproutRate)

HWHerbPoleLoss[Area] = HerbicideEffect[Area]*HWPole[Area]*HWHerbPercent[Area]

HWSilviLoss[Area] = HWPole[Area]*HWPolePercentCut[Area]*HWSilvi[Area]

HWSapling[**AREA**](t) = HWSapling[**AREA**](t - dt) + (HWRegeneration[**AREA**] - HWSapToPole[**AREA**] - HWSapMort[**AREA**]) * dt

TRANSIT TIME = 15
INFLOW LIMIT = INF
CAPACITY = INF

INIT HWSapling[A1] = 17000
INIT HWSapling[A2] = 14000
INIT HWSapling[A3] = 12750
INIT HWSapling[A4] = 12500
INIT HWSapling[A5] = 12250
INIT HWSapling[A6] = 1200
INIT HWSapling[A7] = 13750
INIT HWSapling[A8] = 13750
INIT HWSapling[A9] = 9750
INIT HWSapling[A10] = 13000
INIT HWSapling[A11] = 15750
INIT HWSapling[A12] = 16250
INIT HWSapling[A13] = 16750
INIT HWSapling[A14] = 15250
INIT HWSapling[A15] = 16250
INIT HWSapling[A16] = 17500
INIT HWSapling[A17] = 10750
INIT HWSapling[A18] = 16250
INIT HWSapling[A19] = 21500
INIT HWSapling[A20] = 11000

INFLOWS:

HWRegeneration[Area] = HWPole[Area]*HWSeeding[Area]

OUTFLOWS:

HWSapToPole[Area] = CONVEYOR OUTFLOW
HWSapMort[Area] = LEAKAGE OUTFLOW

LEAKAGE FRACTION = HWSapMortRate[Area]+HWSapFireLoss[Area]
NO-LEAK ZONE = 0

HWFactor[Area] = HWSapDen[Area]*1.5+HWPoleDen[Area]*2

HWPoleDen[Area] = HWPole[Area]/Acreage[Area]

HWResproutRate = 0.5

HWSapDen[Area] = HWSapling[Area]/Acreage[Area]

HWPoleFireLoss[Area] = GRAPH(Fire[Area])

(0.00, 0.00), (0.1, 0.229), (0.2, 0.397), (0.3, 0.487), (0.4, 0.525), (0.5, 0.574), (0.6, 0.607), (0.7, 0.637), (0.8, 0.664), (0.9, 0.694), (1, 0.716)

HWPoleMortRate[Area] = GRAPH(HWPoleDen[Area])

(0.00, 0.05), (10.0, 0.0635), (20.0, 0.0927), (30.0, 0.117), (40.0, 0.145), (50.0, 0.173), (60.0, 0.235), (70.0, 0.292), (80.0, 0.406), (90.0, 0.577), (100, 1.00)

HWSapFireLoss[Area] = GRAPH(Fire[Area])

(0.00, 0.00), (0.1, 0.31), (0.2, 0.504), (0.3, 0.617), (0.4, 0.689), (0.5, 0.743), (0.6, 0.788), (0.7, 0.824), (0.8, 0.842), (0.9, 0.873), (1, 0.9)

HWSapMortRate[Area] = GRAPH(HWSapDen[Area])

(0.00, 0.00), (60.0, 0.02), (120, 0.04), (180, 0.08), (240, 0.12), (300, 0.16), (360, 0.22), (420, 0.305), (480, 0.42), (540, 0.595), (600, 0.89)

HWSeeding[Area] = GRAPH(HWSapDen[Area])

(0.00, 15.0), (60.0, 10.5), (120, 6.60), (180, 4.72), (240, 3.38), (300, 2.10), (360, 1.27), (420, 0.825), (480, 0.375), (540, 0.15), (600, 0.00)

Herbicide

HerbicideEffect[Area](t) = HerbicideEffect[Area](t - dt) + (HerbApplied[Area] - HerbThru[Area]) * dt

INIT HerbicideEffect[Area] = 0

INFLOWS:

HerbApplied[Area] = HerbFactor[Area]

OUTFLOWS:

HerbThru[Area] = HerbicideEffect[Area]

HerbFactor[Area] = Pulse(0.95,FirstHerb[Area],HerbFreq)*HerbYesNo[Area]

HWHerbPercent[Area] = 1

Longleaf Pine

LLFLargePole[**AREA**](t) = LLFLargePole[**AREA**](t - dt) + (LLFSPoleToLPole[**AREA**] + LLFPltSPoleToLPole[**AREA**] - LLFLPoleToMat[**AREA**] - LLFLPoleMort[**AREA**]) * dt

TRANSIT TIME = 30
INFLOW LIMIT = INF
CAPACITY = INF

INIT LLFLargePole[A1] = 8126
INIT LLFLargePole[A2] = 2890
INIT LLFLargePole[A3] = 3230
INIT LLFLargePole[A4] = 8704
INIT LLFLargePole[A5] = 3910
INIT LLFLargePole[A6] = 4828
INIT LLFLargePole[A7] = 2380
INIT LLFLargePole[A8] = 748
INIT LLFLargePole[A9] = 1496
INIT LLFLargePole[A10] = 14688
INIT LLFLargePole[A11] = 1428
INIT LLFLargePole[A12] = 1972
INIT LLFLargePole[A13] = 1156
INIT LLFLargePole[A14] = 6834
INIT LLFLargePole[A15] = 6698
INIT LLFLargePole[A16] = 3468
INIT LLFLargePole[A17] = 2346
INIT LLFLargePole[A18] = 1666
INIT LLFLargePole[A19] = 7208
INIT LLFLargePole[A20] = 13090

INFLOWS:

LLFSPoleToLPole[Area] = CONVEYOR OUTFLOW
LLFPltSPoleToLPole[Area] = CONVEYOR OUTFLOW

OUTFLOWS:

LLFLPoleToMat[Area] = CONVEYOR OUTFLOW
LLFLPoleMort[Area] = LEAKAGE OUTFLOW
LEAKAGE FRACTION =
LLFLPoleMortRate[Area]+LLFLPoleFireLoss[Area]*FireMortMag+LLFLPolePercentCut[Area]*
LLFSilvi[Area]

NO-LEAK ZONE = 0

LLFMature[**AREA**](t) = LLFMature[**AREA**](t - dt) + (LLFLPoleToMat[**AREA**] - LLFMatToOG[**AREA**] - LLFMatureMort[**AREA**]) * dt

TRANSIT TIME = 30
INFLOW LIMIT = INF
CAPACITY = INF

INIT LLFMature[A1] = 7128
INIT LLFMature[A2] = 2706
INIT LLFMature[A3] = 2442
INIT LLFMature[A4] = 924
INIT LLFMature[A5] = 5412
INIT LLFMature[A6] = 1848
INIT LLFMature[A7] = 858
INIT LLFMature[A8] = 6270
INIT LLFMature[A9] = 2508
INIT LLFMature[A10] = 1848
INIT LLFMature[A11] = 1716
INIT LLFMature[A12] = 3300
INIT LLFMature[A13] = 3828
INIT LLFMature[A14] = 1188
INIT LLFMature[A15] = 6864
INIT LLFMature[A16] = 2706
INIT LLFMature[A17] = 3564
INIT LLFMature[A18] = 3498
INIT LLFMature[A19] = 5346
INIT LLFMature[A20] = 8712

INFLOWS:

LLFLPoleToMat[Area] = CONVEYOR OUTFLOW

OUTFLOWS:

LLFMatToOG[Area] = CONVEYOR OUTFLOW
LLFMatureMort[Area] = LEAKAGE OUTFLOW

LEAKAGE FRACTION =
LLFMatMortRate[Area]+LLFMatureFireLoss[Area]*FireMortMag+LLFMaturePercentCut[Area]*
LLFSilvi[Area]

NO-LEAK ZONE = 0

LLFOG[**AREA**](t) = LLFOG[**AREA**](t - dt) + (LLFMatToOG[**AREA**] - LLFOGMort[**AREA**]) * dt

INIT LLFOG[A1] = 3672
INIT LLFOG[A2] = 1394
INIT LLFOG[A3] = 1258
INIT LLFOG[A4] = 476
INIT LLFOG[A5] = 2788
INIT LLFOG[A6] = 952
INIT LLFOG[A7] = 442
INIT LLFOG[A8] = 3230
INIT LLFOG[A9] = 1292
INIT LLFOG[A10] = 952
INIT LLFOG[A11] = 884
INIT LLFOG[A12] = 1700
INIT LLFOG[A13] = 1972
INIT LLFOG[A14] = 612
INIT LLFOG[A15] = 3536
INIT LLFOG[A16] = 1394
INIT LLFOG[A17] = 1836
INIT LLFOG[A18] = 1802
INIT LLFOG[A19] = 2754
INIT LLFOG[A20] = 4488

INFLOWS:

LLFMatToOG[Area] = CONVEYOR OUTFLOW

OUTFLOWS:

LLFOGMort[Area] = LLFOG[Area]*(LLFOGMortRate[Area]+LLFOGFireLoss
[Area]*FireMortMag+LLFOGPercentCut[Area]*L
LFSilvi[Area])
LLFPlantedSapling[**AREA**](t) = LLFPlantedSapling[**AREA**](t - dt) + (LLFPltSeedToSap[**AREA**] -
LLFPltSapToSPole[**AREA**] - LLFPltSapMort[**AREA**]) * dt

TRANSIT TIME = 10
INFLOW LIMIT = INF
CAPACITY = INF

INIT LLFPlantedSapling[A1] = 0,0,0,0,0,0,0,0,0,5
INIT LLFPlantedSapling[A2] = 0,0,0,0,0,0,0,0,0,0
INIT LLFPlantedSapling[A3] = 0,0,0,0,0,0,0,0,0,0
INIT LLFPlantedSapling[A4] = 0,0,0,0,0,0,0,0,0,0
INIT LLFPlantedSapling[A5] = 0,0,0,0,0,0,0,0,0,5
INIT LLFPlantedSapling[A6] = 0,0,0,0,0,0,0,0,0,0
INIT LLFPlantedSapling[A7] = 0,0,0,0,0,0,0,0,0,0
INIT LLFPlantedSapling[A8] = 0,0,0,0,0,0,0,0,0,20
INIT LLFPlantedSapling[A9] = 0,0,0,0,0,0,0,0,0,0
INIT LLFPlantedSapling[A10] = 0,0,0,0,0,0,0,0,0,0
INIT LLFPlantedSapling[A11] = 0,0,0,0,0,0,0,0,0,0
INIT LLFPlantedSapling[A12] = 0,0,0,0,0,0,0,0,0,0
INIT LLFPlantedSapling[A13] = 0,0,0,0,0,0,0,0,0,0
INIT LLFPlantedSapling[A14] = 0,0,0,0,0,0,0,0,0,0
INIT LLFPlantedSapling[A15] = 0,0,0,0,0,0,0,0,0,0
INIT LLFPlantedSapling[A16] = 0,0,0,0,0,0,0,0,0,0
INIT LLFPlantedSapling[A17] = 0,0,0,0,0,0,0,0,0,0
INIT LLFPlantedSapling[A18] = 0,0,0,0,0,0,0,45,0,30
INIT LLFPlantedSapling[A19] = 0,0,0,0,0,0,0,0,0,10
INIT LLFPlantedSapling[A20] = 0,0,0,0,0,0,0,30,0,15

INFLOWS:

LLFPltSeedToSap[Area] = LLFPlantedSeedling[Area]

OUTFLOWS:

LLFPltSapToSPole[Area] = CONVEYOR OUTFLOW
LLFPltSapMort[Area] = LEAKAGE OUTFLOW

LEAKAGE FRACTION =
LLFPlantedSapMortRate+LLFSapFireLoss[Area]*PltLLFFireProtection

NO-LEAK ZONE = 0

LLFPlantedSeedling[**AREA**](t) = LLFPlantedSeedling[**AREA**](t - dt) + (LLFPlanted[**AREA**] - LLFPltSeedMort[**AREA**] - LLFPltSeedToSap[**AREA**]) * dt

INIT LLFPlantedSeedling[A1] = 0
INIT LLFPlantedSeedling[A2] = 0
INIT LLFPlantedSeedling[A3] = 10
INIT LLFPlantedSeedling[A4] = 0
INIT LLFPlantedSeedling[A5] = 0
INIT LLFPlantedSeedling[A6] = 0
INIT LLFPlantedSeedling[A7] = 15
INIT LLFPlantedSeedling[A8] = 0
INIT LLFPlantedSeedling[A9] = 0
INIT LLFPlantedSeedling[A10] = 10
INIT LLFPlantedSeedling[A11] = 0
INIT LLFPlantedSeedling[A12] = 20
INIT LLFPlantedSeedling[A13] = 0
INIT LLFPlantedSeedling[A14] = 0
INIT LLFPlantedSeedling[A15] = 0
INIT LLFPlantedSeedling[A16] = 0
INIT LLFPlantedSeedling[A17] = 20
INIT LLFPlantedSeedling[A18] = 0
INIT LLFPlantedSeedling[A19] = 0
INIT LLFPlantedSeedling[A20] = 0

INFLOWS:

LLFPlanted[Area] = DELAY(LLFPlantRate[Area],LLFPlantDelay,0)

OUTFLOWS:

LLFPltSeedMort[Area] =
LLFPlantedSeedling[Area]*(PltLLFFireProtection*LLFSeedFireLoss[Area]+LLFPlantedSeedMortRate)

LLFPltSeedToSap[Area] = LLFPlantedSeedling[Area]

LLFPlantedSmallPole[Area](t) = LLFPlantedSmallPole[Area](t - dt) + (LLFPltSapToSPole[Area] - LLFPltSPoleToLPole[Area] - LLFPltSPoleMort[Area]) * dt

INIT LLFPlantedSmallPole[Area] = 0

INFLOWS:

LLFPltSapToSPole[Area] = CONVEYOR OUTFLOW

OUTFLOWS:

LLFPltSPoleToLPole[Area] = CONVEYOR OUTFLOW
LLFPltSPoleMort[Area] = LEAKAGE OUTFLOW

LEAKAGE FRACTION = LLFPlantedSPoleMortRate+LLFSPoleFireLoss[Area]

NO-LEAK ZONE = 0

LLFSapling[**AREA**](t) = LLFSapling[**AREA**](t - dt) + (LLFSeedToSap[**AREA**] - LLFSapToSPole[**AREA**] - LLFSapMort[**AREA**]) * dt

TRANSIT TIME = 10
INFLOW LIMIT = INF
CAPACITY = INF

INIT LLFSapling[A1] = 36000
INIT LLFSapling[A2] = 51000
INIT LLFSapling[A3] = 48000
INIT LLFSapling[A4] = 20000
INIT LLFSapling[A5] = 46000
INIT LLFSapling[A6] = 31000
INIT LLFSapling[A7] = 9000
INIT LLFSapling[A8] = 51000
INIT LLFSapling[A9] = 39000
INIT LLFSapling[A10] = 28000
INIT LLFSapling[A11] = 15000
INIT LLFSapling[A12] = 46000
INIT LLFSapling[A13] = 43000
INIT LLFSapling[A14] = 22000
INIT LLFSapling[A15] = 30000
INIT LLFSapling[A16] = 26000
INIT LLFSapling[A17] = 31000
INIT LLFSapling[A18] = 24000
INIT LLFSapling[A19] = 36000
INIT LLFSapling[A20] = 66000

INFLOWS:

LLFSeedToSap[Area] = CONVEYOR OUTFLOW

OUTFLOWS:

LLFSapToSPole[Area] = CONVEYOR OUTFLOW
LLFSapMort[Area] = LEAKAGE OUTFLOW

LEAKAGE FRACTION = LLFSapMortRate[Area]+LLFSapFireLoss[Area]

NO-LEAK ZONE = 0

LLFSeedling[**AREA**](t) = LLFSeedling[**AREA**](t - dt) + (LLFRegeneration[**AREA**] - LLFSeedMort[**AREA**] - LLFSeedToSap[**AREA**]) * dt

TRANSIT TIME = 5
INFLOW LIMIT = INF
CAPACITY = INF

INIT LLFSeedling[A1] = 90000
INIT LLFSeedling[A2] = 127500
INIT LLFSeedling[A3] = 120000
INIT LLFSeedling[A4] = 50000
INIT LLFSeedling[A5] = 115000
INIT LLFSeedling[A6] = 77500
INIT LLFSeedling[A7] = 22500
INIT LLFSeedling[A8] = 127500
INIT LLFSeedling[A9] = 97500
INIT LLFSeedling[A10] = 70000
INIT LLFSeedling[A11] = 37500
INIT LLFSeedling[A12] = 115000
INIT LLFSeedling[A13] = 107500
INIT LLFSeedling[A14] = 55000
INIT LLFSeedling[A15] = 75000
INIT LLFSeedling[A16] = 65000
INIT LLFSeedling[A17] = 77500
INIT LLFSeedling[A18] = 60000
INIT LLFSeedling[A19] = 90000
INIT LLFSeedling[A20] = 165000

INFLOWS:

LLFRegeneration[Area] =
LLFSeeding*LLFSeedTrees[Area]*LLFHWchoke[Area]*LLFFireEffect[Area]*LLFShadeEffect[Area]

OUTFLOWS:

LLFSeedMort[Area] = LEAKAGE OUTFLOW

LEAKAGE FRACTION = LLFSeedMortRate[Area]+LLFSeedFireLoss[Area]

NO-LEAK ZONE = 0

LLFSeedToSap[Area] = CONVEYOR OUTFLOW

LLFSmallPole[**AREA**](t) = LLFSmallPole[**AREA**](t - dt) + (LLFSapToSPole[**AREA**] - LLFSPoleMort[**AREA**] - LLFSPoleToLPole[**AREA**]) * dt

TRANSIT TIME = 15
INFLOW LIMIT = INF
CAPACITY = INF

INIT LLFSmallPole[A1] = 25410
INIT LLFSmallPole[A2] = 5610
INIT LLFSmallPole[A3] = 6270
INIT LLFSmallPole[A4] = 16896
INIT LLFSmallPole[A5] = 7590
INIT LLFSmallPole[A6] = 9372
INIT LLFSmallPole[A7] = 4620
INIT LLFSmallPole[A8] = 1452
INIT LLFSmallPole[A9] = 2904
INIT LLFSmallPole[A10] = 28512
INIT LLFSmallPole[A11] = 2772
INIT LLFSmallPole[A12] = 3828
INIT LLFSmallPole[A13] = 2244
INIT LLFSmallPole[A14] = 13266
INIT LLFSmallPole[A15] = 13002
INIT LLFSmallPole[A16] = 6732
INIT LLFSmallPole[A17] = 4554
INIT LLFSmallPole[A18] = 3234
INIT LLFSmallPole[A19] = 13992
INIT LLFSmallPole[A20] = 9240

INFLOWS:

LLFSapToSPole[Area] = CONVEYOR OUTFLOW

OUTFLOWS:

LLFSPoleMort[Area] = LEAKAGE OUTFLOW

LEAKAGE FRACTION = LLFSPoleMortRate[Area]+LLFSPoleFireLoss[Area]*FireMortMag+LLFSPolePercentCut[Area]* LLFSilvi[Area]

NO-LEAK ZONE = 0

LLFSPoleToLPole[Area] = CONVEYOR OUTFLOW

FireMortMag = 0.5

LLFLPoleDen[Area] = LLFLargePole[Area]/LLFAreaAcreage[Area]

LLFMatureDen[Area] = LLFMature[Area]/LLFAreaAcreage[Area]

LLFOGDen[Area] = LLFOG[Area]/LLFAreaAcreage[Area]

LLFPlantDelay = 3

LLFPlantedSapMortRate = 0.075

LLFPlantedSeeding = 500

LLFPlantedSeedMortRate = 0.15

LLFPlantedSPoleMortRate = 0.01

LLFPlantRate[Area] = LLFConversion[Area]*LLFPlantedSeeding

LLFPltSapDen[Area] = IF(LLFAreaConvertedAcreage[Area]=0)THEN(0)ELSE(LLFPlantedSapling[Area]/ LLFAreaConvertedAcreage[Area])

LLFPltSeedDen[Area] =
IF(LLFAreaConvertedAcreage[Area]=0)THEN(0)ELSE(LLFPlantedSeedling[Area]/
LLFAreaConvertedAcreage[Area])

LLFPltSPoleDen[Area] =
IF(LLFAreaConvertedAcreage[Area]=0)THEN(0)ELSE(LLFPlantedSmallPole[Area]/
LLFAreaConvertedAcreage[Area])

LLFSaplingDen[Area] = LLFSapling[Area]/LLFAreaAcreage[Area]

LLFSeeding = 30

LLFSeedlingDen[Area] = LLFSeedling[Area]/LLFAreaAcreage[Area]

LLFSeedTrees[Area] = LLFLargePole[Area]*0.25+LLFMature[Area]+LLFOG[Area]*0.5

LLFSPoleDen[Area] = LLFSmallPole[Area]/LLFAreaAcreage[Area]

LLFTreeDen[Area] = LLFTrees[Area]/LLFAreaAcreage[Area]

LLFTrees[Area] = LLFSmallPole[Area]*0.75+LLFLargePole[Area]+LLFMature[Area]+LLFOG[Area]

LLFFireEffect[Area] = GRAPH(FireEffect[Area])

(0.00, 0.1), (0.1, 0.19), (0.2, 0.26), (0.3, 0.34), (0.4, 0.43), (0.5, 0.53), (0.6, 0.62), (0.7, 0.71), (0.8, 0.81), (0.9, 0.91), (1, 1.00)

LLFHWchoke[Area] = GRAPH(HWFactor[Area])

(0.00, 1.00), (50.0, 0.94), (100, 0.87), (150, 0.775), (200, 0.67), (250, 0.515), (300, 0.37), (350, 0.195), (400, 0.095), (450, 0.04), (500, 0.00)

LLFLPoleFireLoss[Area] = GRAPH(Fire[Area])

(0.00, 0.00), (0.1, 0.00), (0.2, 0.00), (0.3, 0.005), (0.4, 0.02), (0.5, 0.045), (0.6, 0.08), (0.7, 0.15), (0.8, 0.245), (0.9, 0.365), (1, 0.6)

LLFLPoleMortRate[Area] = GRAPH(LLFLPoleDen[Area])

(0.00, 0.02), (15.0, 0.02), (30.0, 0.02), (45.0, 0.02), (60.0, 0.02), (75.0, 0.02), (90.0, 0.02), (105, 0.0275), (120, 0.0375), (135, 0.075), (150, 0.151)

LLFMatMortRate[Area] = GRAPH(LLFMatureDen[Area])

(0.00, 0.02), (10.0, 0.02), (20.0, 0.02), (30.0, 0.02), (40.0, 0.02), (50.0, 0.02), (60.0, 0.02), (70.0, 0.0288), (80.0, 0.05), (90.0, 0.0825), (100, 0.154)

LLFMatureFireLoss[Area] = GRAPH(Fire[Area])

(0.00, 0.00), (0.1, 0.00), (0.2, 0.00), (0.3, 0.00), (0.4, 0.00), (0.5, 0.00), (0.6, 0.005), (0.7, 0.02), (0.8, 0.08), (0.9, 0.175), (1, 0.5)

LLFOGFireLoss[Area] = GRAPH(Fire[Area])

(0.00, 0.00), (0.1, 0.00), (0.2, 0.00), (0.3, 0.00), (0.4, 0.00), (0.5, 0.00), (0.6, 0.00), (0.7, 0.005), (0.8, 0.065), (0.9, 0.14), (1, 0.3)

LLFOGMortRate[Area] = GRAPH(LLFOGDen[Area])

(0.00, 0.0138), (3.00, 0.0138), (6.00, 0.0138), (9.00, 0.0138), (12.0, 0.0138), (15.0, 0.0138), (18.0, 0.0138), (21.0, 0.015), (24.0, 0.0238), (27.0, 0.045), (30.0, 0.0938)

LLFSapFireLoss[Area] = GRAPH(Fire[Area])

(0.00, 0.00), (0.1, 0.03), (0.2, 0.065), (0.3, 0.1), (0.4, 0.155), (0.5, 0.225), (0.6, 0.3), (0.7, 0.405), (0.8, 0.525), (0.9, 0.72), (1, 1.00)

LLFSapMortRate[Area] = GRAPH(LLFSaplingDen[Area])

(0.00, 0.05), (50.0, 0.05), (100, 0.05), (150, 0.05), (200, 0.05), (250, 0.0513), (300, 0.0537), (350, 0.0563), (400, 0.0638), (450, 0.0938), (500, 0.158)

LLFSeedFireLoss[Area] = GRAPH(Fire[Area])

(0.00, 0.00), (0.1, 0.38), (0.2, 0.56), (0.3, 0.67), (0.4, 0.755), (0.5, 0.82), (0.6, 0.855), (0.7, 0.9), (0.8, 0.93), (0.9, 0.965), (1, 1.00)

LLFSeedMortRate[Area] = GRAPH(LLFSeedlingDen[Area])

(0.00, 0.153), (100, 0.153), (200, 0.153), (300, 0.153), (400, 0.153), (500, 0.153), (600, 0.153), (700, 0.168), (800, 0.188), (900, 0.22), (1000, 0.27)

LLFShadeEffect[Area] = GRAPH(LLFTreeDen[Area])

(0.00, 1.00), (50.0, 0.745), (100, 0.58), (150, 0.43), (200, 0.315), (250, 0.22), (300, 0.16), (350, 0.105), (400, 0.07), (450, 0.035), (500, 0.005)

LLFSPoleFireLoss[Area] = GRAPH(Fire[Area])

(0.00, 0.00), (0.1, 0.00), (0.2, 0.00), (0.3, 0.01), (0.4, 0.02), (0.5, 0.05), (0.6, 0.08), (0.7, 0.16), (0.8, 0.255), (0.9, 0.42), (1, 0.69)

LLFSPoleMortRate[Area] = GRAPH(LLFSPoleDen[Area])

(0.00, 0.0325), (30.0, 0.0325), (60.0, 0.0325), (90.0, 0.0325), (120, 0.0325), (150, 0.0325), (180, 0.0325), (210, 0.0325), (240, 0.0388), (270, 0.0588), (300, 0.149)

Red-Cockaded Woodpecker

RCW_AgeF**[AREA,AGE]**(t) = RCW_AgeF**[AREA,AGE]**(t - dt) + (RCW_MatureF**[AREA,AGE]** + RCW_ImmF**[AREA,AGE]** + RCW_TransF**[AREA,AGE]** + RCW_AgeInF**[AREA,AGE]** - RCW_MortF**[AREA,AGE]** - RCW_DispF**[AREA,AGE]** - RCW_AgeUpF**[AREA,AGE]**) * dt

INIT RCW_AgeF[A1,Age1] = 0
INIT RCW_AgeF[A1,Age2] = 0
INIT RCW_AgeF[A1,Age3] = 0
INIT RCW_AgeF[A1,Age4] = 0
INIT RCW_AgeF[A1,Age5plus] = 0
INIT RCW_AgeF[A2,Age1] = 0
INIT RCW_AgeF[A2,Age2] = 0
INIT RCW_AgeF[A2,Age3] = 1
INIT RCW_AgeF[A2,Age4] = 0
INIT RCW_AgeF[A2,Age5plus] = 0
INIT RCW_AgeF[A3,Age1] = 0
INIT RCW_AgeF[A3,Age2] = 0
INIT RCW_AgeF[A3,Age3] = 0
INIT RCW_AgeF[A3,Age4] = 0
INIT RCW_AgeF[A3,Age5plus] = 0
INIT RCW_AgeF[A4,Age1] = 0
INIT RCW_AgeF[A4,Age2] = 0
INIT RCW_AgeF[A4,Age3] = 0

```
INIT RCW_AgeF[A4,Age4] = 0
INIT RCW_AgeF[A4,Age5plus] = 0
INIT RCW_AgeF[A5,Age1] = 0
INIT RCW_AgeF[A5,Age2] = 0
INIT RCW_AgeF[A5,Age3] = 0
INIT RCW_AgeF[A5,Age4] = 0
INIT RCW_AgeF[A5,Age5plus] = 0
INIT RCW_AgeF[A6,Age1] = 0
INIT RCW_AgeF[A6,Age2] = 0
INIT RCW_AgeF[A6,Age3] = 0
INIT RCW_AgeF[A6,Age4] = 0
INIT RCW_AgeF[A6,Age5plus] = 0
INIT RCW_AgeF[A7,Age1] = 0
INIT RCW_AgeF[A7,Age2] = 0
INIT RCW_AgeF[A7,Age3] = 0
INIT RCW_AgeF[A7,Age4] = 0
INIT RCW_AgeF[A7,Age5plus] = 0
INIT RCW_AgeF[A8,Age1] = 0
INIT RCW_AgeF[A8,Age2] = 1
INIT RCW_AgeF[A8,Age3] = 0
INIT RCW_AgeF[A8,Age4] = 0
INIT RCW_AgeF[A8,Age5plus] = 0
INIT RCW_AgeF[A9,Age1] = 0
INIT RCW_AgeF[A9,Age2] = 0
INIT RCW_AgeF[A9,Age3] = 0
INIT RCW_AgeF[A9,Age4] = 0
INIT RCW_AgeF[A9,Age5plus] = 0
INIT RCW_AgeF[A10,Age1] = 0
INIT RCW_AgeF[A10,Age2] = 0
INIT RCW_AgeF[A10,Age3] = 0
INIT RCW_AgeF[A10,Age4] = 0
INIT RCW_AgeF[A10,Age5plus] = 0
INIT RCW_AgeF[A11,Age1] = 0
INIT RCW_AgeF[A11,Age2] = 0
INIT RCW_AgeF[A11,Age3] = 0
INIT RCW_AgeF[A11,Age4] = 0
INIT RCW_AgeF[A11,Age5plus] = 0
INIT RCW_AgeF[A12,Age1] = 0
INIT RCW_AgeF[A12,Age2] = 0
INIT RCW_AgeF[A12,Age3] = 0
INIT RCW_AgeF[A12,Age4] = 1
INIT RCW_AgeF[A12,Age5plus] = 0
INIT RCW_AgeF[A13,Age1] = 0
INIT RCW_AgeF[A13,Age2] = 0
INIT RCW_AgeF[A13,Age3] = 0
INIT RCW_AgeF[A13,Age4] = 0
INIT RCW_AgeF[A13,Age5plus] = 0
INIT RCW_AgeF[A14,Age1] = 0
INIT RCW_AgeF[A14,Age2] = 0
INIT RCW_AgeF[A14,Age3] = 0
INIT RCW_AgeF[A14,Age4] = 0
INIT RCW_AgeF[A14,Age5plus] = 0
INIT RCW_AgeF[A15,Age1] = 0
INIT RCW_AgeF[A15,Age2] = 0
INIT RCW_AgeF[A15,Age3] = 0
INIT RCW_AgeF[A15,Age4] = 0
INIT RCW_AgeF[A15,Age5plus] = 0
INIT RCW_AgeF[A16,Age1] = 0
INIT RCW_AgeF[A16,Age2] = 0
INIT RCW_AgeF[A16,Age3] = 0
INIT RCW_AgeF[A16,Age4] = 0
INIT RCW_AgeF[A16,Age5plus] = 0
INIT RCW_AgeF[A17,Age1] = 0
INIT RCW_AgeF[A17,Age2] = 0
INIT RCW_AgeF[A17,Age3] = 1
INIT RCW_AgeF[A17,Age4] = 0
INIT RCW_AgeF[A17,Age5plus] = 0
INIT RCW_AgeF[A18,Age1] = 0
INIT RCW_AgeF[A18,Age2] = 0
INIT RCW_AgeF[A18,Age3] = 0
INIT RCW_AgeF[A18,Age4] = 0
INIT RCW_AgeF[A18,Age5plus] = 0
INIT RCW_AgeF[A19,Age1] = 0
INIT RCW_AgeF[A19,Age2] = 0
INIT RCW_AgeF[A19,Age3] = 0
INIT RCW_AgeF[A19,Age4] = 0
INIT RCW_AgeF[A19,Age5plus] = 0
INIT RCW_AgeF[A20,Age1] = 0
INIT RCW_AgeF[A20,Age2] = 0
INIT RCW_AgeF[A20,Age3] = 0
INIT RCW_AgeF[A20,Age4] = 1
INIT RCW_AgeF[A20,Age5plus] = 0
```

<u>INFLOWS</u>:

```
RCW_ImmF[Area,AgeGroup] =
IF(RCW_AreaF[Area]>0)THEN(0)ELSE(RCW_ImmTotF[Area,AgeGroup])

RCW_TransF[Area,AgeGroup] = RCW_Translocation[Area]*RCW_FTrans[Area,AgeGroup]

RCW_MatureF[Area,AgeGroup] = RCW_FledglingF[Area]-RCW_FledgDispF[Area]-
RCW_FledgMortF[Area]

RCW_AgeInF[Area,AgeGroup] =
IF(RCW_AgeGroup[AgeGroup]=2)THEN(RCW_AgeUpF[Area,Age1])ELSE(
IF(RCW_AgeGroup[AgeGroup]=3)THEN(RCW_AgeUpF[Area,Age2])ELSE(
IF(RCW_AgeGroup[AgeGroup]=4)THEN(RCW_AgeUpF[Area,Age3])ELSE(
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IF(RCW_AgeGroup[AgeGroup]=5)THEN(RCW_AgeUpF[Area,Age4])ELSE(
IF(RCW_AgeGroup[AgeGroup]=6)THEN(RCW_AgeUpF[Area,Age5plus])ELSE(0)))))

OUTFLOWS:

RCW_MortF[Area,AgeGroup] =
ROUND(RCW_AgeF[Area,AgeGroup]*RCW_MortRate[Area]*RCWFemaleMortAdd*RCWMortMag)

RCW_DispF[Area,AgeGroup] =
ROUND(IF(RCW_AreaF[Area]>=1)THEN(
IF((RCW_AreaF[Area]-RCW_AgeF[Area,Age1])<1)THEN(RCW_AreaF[Area]-RCW_AgeF[Area,Age1]-RCW_MortF[Area,Age1])ELSE(
IF((RCW_AreaF[Area]-RCW_AgeF[Area,Age1]-RCW_AgeF[Area,Age2])<1)
THEN(RCW_AreaF[Area]-RCW_AgeF[Area,Age1]-RCW_MortF[Area,Age1]-RCW_AgeF[Area,Age2]-RCW_MortF[Area,Age2])ELSE(
IF((RCW_AreaF[Area]-RCW_AgeF[Area,Age1]-RCW_AgeF[Area,Age2] -RCW_AgeF[Area,Age3])<1)
THEN(RCW_AreaF [Area]-RCW_AgeF[Area,Age1]-RCW_MortF[Area,Age1]-RCW_AgeF[Area,Age2]-RCW_MortF[Area,Age2]-RCW_AgeF[Area,Age3]-RCW_MortF[Area,Age3])ELSE(
RCW_AreaF[Area]-RCW_AgeF[Area,Age1]-RCW_MortF[Area,Age1]-RCW_AgeF[Area,Age2]-RCW_MortF[Area,Age2]-RCW_AgeF[Area,Age3]-RCW_MortF[Area,Age3]-RCW_AgeF[Area,Age4]-RCW_MortF[Area,Age4])))) ELSE(IF(RCW_AgeGroup[AgeGroup]<>5)
THEN(RCW_DispDecisionF[Area]*(RCW_AgeF[Area,AgeGroup]-RCW_MortF[Area,AgeGroup]))ELSE(0)))*DispSwitch

RCW_AgeUpF[Area,AgeGroup] =
IF(RCW_AgeGroup[AgeGroup]<>5)THEN(RCW_AgeF[Area,AgeGroup]-RCW_DispF[Area,AgeGroup]-RCW_MortF[Area,AgeGroup])ELSE(0)

RCW_AgeM[**AREA,AGE**](t) = RCW_AgeM[**AREA,AGE**](t - dt) + (RCW_MatureM[**AREA,AGE**] + RCW_ImmM[**AREA,AGE**] + RCW_TransM[**AREA,AGE**] + RCW_AgeInM[**AREA,AGE**] - RCW_MortM[**AREA,AGE**] - RCW_DispM[**AREA,AGE**] - RCW_AgeUpM[**AREA,AGE**]) * dt

INIT RCW_AgeM[A1,Age1] = 0
INIT RCW_AgeM[A1,Age2] = 0
INIT RCW_AgeM[A1,Age3] = 0
INIT RCW_AgeM[A1,Age4] = 0
INIT RCW_AgeM[A1,Age5plus] = 0
INIT RCW_AgeM[A2,Age1] = 1
INIT RCW_AgeM[A2,Age2] = 0
INIT RCW_AgeM[A2,Age3] = 0
INIT RCW_AgeM[A2,Age4] = 1
INIT RCW_AgeM[A2,Age5plus] = 0
INIT RCW_AgeM[A3,Age1] = 0
INIT RCW_AgeM[A3,Age2] = 0
INIT RCW_AgeM[A3,Age3] = 0
INIT RCW_AgeM[A3,Age4] = 0
INIT RCW_AgeM[A3,Age5plus] = 0
INIT RCW_AgeM[A4,Age1] = 0
INIT RCW_AgeM[A4,Age2] = 0
INIT RCW_AgeM[A4,Age3] = 0
INIT RCW_AgeM[A4,Age4] = 0
INIT RCW_AgeM[A4,Age5plus] = 0
INIT RCW_AgeM[A5,Age1] = 0
INIT RCW_AgeM[A5,Age2] = 0
INIT RCW_AgeM[A5,Age3] = 0
INIT RCW_AgeM[A5,Age4] = 0
INIT RCW_AgeM[A5,Age5plus] = 0
INIT RCW_AgeM[A6,Age1] = 0
INIT RCW_AgeM[A6,Age2] = 0
INIT RCW_AgeM[A6,Age3] = 0
INIT RCW_AgeM[A6,Age4] = 0
INIT RCW_AgeM[A6,Age5plus] = 0
INIT RCW_AgeM[A7,Age1] = 0
INIT RCW_AgeM[A7,Age2] = 0
INIT RCW_AgeM[A7,Age3] = 0
INIT RCW_AgeM[A7,Age4] = 0
INIT RCW_AgeM[A7,Age5plus] = 0
INIT RCW_AgeM[A8,Age1] = 1
INIT RCW_AgeM[A8,Age2] = 0
INIT RCW_AgeM[A8,Age3] = 0
INIT RCW_AgeM[A8,Age4] = 1
INIT RCW_AgeM[A8,Age5plus] = 0
INIT RCW_AgeM[A9,Age1] = 0
INIT RCW_AgeM[A9,Age2] = 0
INIT RCW_AgeM[A9,Age3] = 0
INIT RCW_AgeM[A9,Age4] = 0
INIT RCW_AgeM[A9,Age5plus] = 0
INIT RCW_AgeM[A10,Age1] = 0
INIT RCW_AgeM[A10,Age2] = 0
INIT RCW_AgeM[A10,Age3] = 0

INIT RCW_AgeM[A10,Age4] = 0
INIT RCW_AgeM[A10,Age5plus] = 0
INIT RCW_AgeM[A11,Age1] = 0
INIT RCW_AgeM[A11,Age2] = 0
INIT RCW_AgeM[A11,Age3] = 0
INIT RCW_AgeM[A11,Age4] = 0
INIT RCW_AgeM[A11,Age5plus] = 0
INIT RCW_AgeM[A12,Age1] = 1
INIT RCW_AgeM[A12,Age2] = 1
INIT RCW_AgeM[A12,Age3] = 0
INIT RCW_AgeM[A12,Age4] = 0
INIT RCW_AgeM[A12,Age5plus] = 1
INIT RCW_AgeM[A13,Age1] = 0
INIT RCW_AgeM[A13,Age2] = 0
INIT RCW_AgeM[A13,Age3] = 0
INIT RCW_AgeM[A13,Age4] = 0
INIT RCW_AgeM[A13,Age5plus] = 0
INIT RCW_AgeM[A14,Age1] = 0
INIT RCW_AgeM[A14,Age2] = 0
INIT RCW_AgeM[A14,Age3] = 0
INIT RCW_AgeM[A14,Age4] = 0
INIT RCW_AgeM[A14,Age5plus] = 0
INIT RCW_AgeM[A15,Age1] = 0
INIT RCW_AgeM[A15,Age2] = 0
INIT RCW_AgeM[A15,Age3] = 0
INIT RCW_AgeM[A15,Age4] = 0
INIT RCW_AgeM[A15,Age5plus] = 0
INIT RCW_AgeM[A16,Age1] = 0
INIT RCW_AgeM[A16,Age2] = 0
INIT RCW_AgeM[A16,Age3] = 0
INIT RCW_AgeM[A16,Age4] = 0
INIT RCW_AgeM[A16,Age5plus] = 0
INIT RCW_AgeM[A17,Age1] = 0
INIT RCW_AgeM[A17,Age2] = 1
INIT RCW_AgeM[A17,Age3] = 1
INIT RCW_AgeM[A17,Age4] = 0
INIT RCW_AgeM[A17,Age5plus] = 0
INIT RCW_AgeM[A18,Age1] = 0
INIT RCW_AgeM[A18,Age2] = 0
INIT RCW_AgeM[A18,Age3] = 0
INIT RCW_AgeM[A18,Age4] = 0
INIT RCW_AgeM[A18,Age5plus] = 0
INIT RCW_AgeM[A19,Age1] = 0
INIT RCW_AgeM[A19,Age2] = 0
INIT RCW_AgeM[A19,Age3] = 0
INIT RCW_AgeM[A19,Age4] = 0
INIT RCW_AgeM[A19,Age5plus] = 0
INIT RCW_AgeM[A20,Age1] = 1
INIT RCW_AgeM[A20,Age2] = 0
INIT RCW_AgeM[A20,Age3] = 0
INIT RCW_AgeM[A20,Age4] = 0
INIT RCW_AgeM[A20,Age5plus] = 1

INFLOWS:

RCW_ImmM[Area,AgeGroup] =
IF(RCW_AreaTotM[Area]>=2)THEN(0)ELSE(RCW_ImmTotM[Area,AgeGroup])

RCW_TransM[Area,AgeGroup] = RCW_Translocation[Area]*RCW_MTrans[Area,AgeGroup]

RCW_MatureM[Area,AgeGroup] = RCW_FledglingM[Area]-RCW_FledgMortM[Area]-
RCW_FledgDispM[Area]

RCW_AgeInM[Area,AgeGroup] =
IF(RCW_AgeGroup[AgeGroup]=2)THEN(RCW_AgeUpM[Area,Age1])ELSE(
IF(RCW_AgeGroup[AgeGroup]=3)THEN(RCW_AgeUpM[Area,Age2])ELSE(
IF(RCW_AgeGroup[AgeGroup]=4)THEN(RCW_AgeUpM[Area,Age3])ELSE(
IF(RCW_AgeGroup[AgeGroup]=5)THEN(RCW_AgeUpM[Area,Age4])ELSE(
IF(RCW_AgeGroup[AgeGroup]=6)THEN(RCW_AgeUpM[Area,Age5plus])ELSE(0)))))

OUTFLOWS:

RCW_MortM[Area,AgeGroup] =
ROUND(RCW_AgeM[Area,AgeGroup]*RCW_MortRate[Area]*RCWMortMag)

RCW_DispM[Area,AgeGroup] = DispSwitch*(ROUND(
IF(RCW_AreaTotM[Area]>=3)THEN(IF((RCW_AreaTotM[Area]-
RCW_AgeM[Area,Age1])<=5)THEN(RCW_AreaTotM[Area]-RCW_AgeM[Area,Age1]-
RCW_MortM[Area,Age1])ELSE(
IF((RCW_AreaTotM[Area]-RCW_AgeM[Area,Age1]-RCW_AgeM[Area,Age2])<=5)
THEN(RCW_AreaTotM[Area]-RCW_AgeM[Area,Age1]-RCW_MortM[Area,Age1]-
RCW_AgeM[Area,Age2]-RCW_MortM[Area,Age2])ELSE(

IF((RCW_AreaTotM[Area]-RCW_AgeM[Area,Age1]-RCW_AgeM[Area,Age2] -
RCW_AgeM[Area,Age3])<=5)
THEN(RCW_AreaTotM[Area]-RCW_AgeM[Area,Age1]-RCW_MortM[Area,Age1]-
RCW_AgeM[Area,Age2]-RCW_MortM[Area,Age2]-RCW_AgeM[Area,Age3]-
RCW_MortM[Area,Age3])ELSE(
RCW_AreaTotM[Area]-RCW_AgeM[Area,Age1]-RCW_MortM[Area,Age1]-RCW_AgeM[Area,Age2]-
RCW_MortM[Area,Age2]-RCW_AgeM[Area,Age3]-RCW_MortM[Area,Age3]-
RCW_AgeM[Area,Age4]-RCW_MortM[Area,Age4]))))
ELSE(0) AND (IF(RCW_AgeGroup[AgeGroup]<>5)
THEN(RCW_DispDecisionM[Area]*(RCW_AgeM[Area,AgeGroup]-
RCW_MortM[Area,AgeGroup]))ELSE(0))))

RCW_AgeUpM[Area,AgeGroup] =
IF(RCW_AgeGroup[AgeGroup]<>5)THEN(RCW_AgeM[Area,AgeGroup]-
RCW_DispM[Area,AgeGroup]-RCW_MortM[Area,AgeGroup])ELSE(0)

RCW_FledglingF[**AREA**](t) = RCW_FledglingF[**AREA**](t - dt) + (RCW_BirthF[**AREA**] -
RCW_MatureF[**AREA,AGE**] - RCW_MatureF[**AREA,AGE**] - RCW_MatureF[**AREA,AGE**] -
RCW_MatureF[**AREA,AGE**] - RCW_MatureF[**AREA,AGE**] - RCW_FledgMortF[**AREA**] -
RCW_FledgDispF[**AREA**]) * dt

INIT RCW_FledglingF[A1] = 0
INIT RCW_FledglingF[A2] = 1
INIT RCW_FledglingF[A3] = 0
INIT RCW_FledglingF[A4] = 0
INIT RCW_FledglingF[A5] = 0
INIT RCW_FledglingF[A6] = 0
INIT RCW_FledglingF[A7] = 0
INIT RCW_FledglingF[A8] = 0
INIT RCW_FledglingF[A9] = 0
INIT RCW_FledglingF[A10] = 0
INIT RCW_FledglingF[A11] = 0
INIT RCW_FledglingF[A12] = 1
INIT RCW_FledglingF[A13] = 0
INIT RCW_FledglingF[A14] = 0
INIT RCW_FledglingF[A15] = 0
INIT RCW_FledglingF[A16] = 0
INIT RCW_FledglingF[A17] = 1
INIT RCW_FledglingF[A18] = 0
INIT RCW_FledglingF[A19] = 0
INIT RCW_FledglingF[A20] = 2

INFLOWS:

RCW_BirthF[Area] = ROUND(RCW_BirthRateF[Area])

OUTFLOWS:

RCW_FledgMortF[Area] =
ROUND(RCW_FledglingF[Area]*RCW_FledgMortRate[Area]*RCW_HelperEffect[Area]*
RCWFemaleMortAdd*RCWMortMag)

RCW_FledgDispF[Area] = ROUND(
IF(RCW_AreaF[Area]>=1)THEN(RCW_FledglingF[Area]-RCW_FledgMortF[Area])ELSE(
RCW_FledgDispDecisionF[Area]*(RCW_FledglingF[Area]-RCW_FledgMortF[Area])))*DispSwitch

RCW_MatureF[Area,AgeGroup] = RCW_FledglingF[Area]-RCW_FledgDispF[Area]-
RCW_FledgMortF[Area]

RCW_FledglingM[**AREA**](t) = RCW_FledglingM[**AREA**](t - dt) + (RCW_BirthM[**AREA**] -
RCW_MatureM[**AREA,AGE**] - RCW_MatureM[**AREA,AGE**] - RCW_MatureM[**AREA,AGE**] -
RCW_MatureM[**AREA,AGE**] - RCW_MatureM[**AREA,AGE**] - RCW_FledgMortM[**AREA**] -
RCW_FledgDispM[**AREA**]) * dt

INIT RCW_FledglingM[A1] = 0
INIT RCW_FledglingM[A2] = 1
INIT RCW_FledglingM[A3] = 0
INIT RCW_FledglingM[A4] = 0
INIT RCW_FledglingM[A5] = 0
INIT RCW_FledglingM[A6] = 0
INIT RCW_FledglingM[A7] = 0
INIT RCW_FledglingM[A8] = 1
INIT RCW_FledglingM[A9] = 0
INIT RCW_FledglingM[A10] = 0
INIT RCW_FledglingM[A11] = 0
INIT RCW_FledglingM[A12] = 0
INIT RCW_FledglingM[A13] = 0
INIT RCW_FledglingM[A14] = 0
INIT RCW_FledglingM[A15] = 0

INIT RCW_FledglingM[A16] = 0
INIT RCW_FledglingM[A17] = 1
INIT RCW_FledglingM[A18] = 0
INIT RCW_FledglingM[A19] = 0
INIT RCW_FledglingM[A20] = 1

INFLOWS:

RCW_BirthM[Area] = ROUND(RCW_BirthRateM[Area])

OUTFLOWS:

RCW_FledgMortM[Area] =
ROUND(RCW_FledglingM[Area]*RCW_FledgMortRate[Area]*RCW_HelperEffect[Area]*RCWMortMag)

RCW_FledgDispM[Area] = ROUND(RCW_FledgDispDecisionM[Area]*(RCW_FledglingM[Area]-RCW_FledgMortM[Area]))*DispSwitch

RCW_MatureM[Area,AgeGroup] = RCW_FledglingM[Area]-RCW_FledgMortM[Area]-RCW_FledgDispM[Area]

AF_1&2&3&4[Area,AgeGroup] =
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=1)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=1)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=1)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=1)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=1)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=2)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=2)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=2)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=2)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=2)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=3)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=3)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=3)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=3)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=3)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=4)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=4)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=4)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=4)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=4)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))))

AF_13&14&15&16[Area,AgeGroup] =
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=13)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=13)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=13)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=13)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=13)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=14)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=14)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=14)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=14)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=14)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=15)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=15)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=15)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=15)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=15)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=16)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=16)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=16)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=16)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+

(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=16)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))))

AF_17&18&19&20[Area,AgeGroup] =
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=17)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=17)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=17)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=17)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=17)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=18)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=18)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=18)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=18)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=18)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=19)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=19)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=19)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=19)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=19)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=20)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=20)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=20)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=20)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=20)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))))

AF_5&6&7&8[Area,AgeGroup] =
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=5)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=5)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=5)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=5)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=5)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=6)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=6)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=6)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=6)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=6)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=7)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=7)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=7)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=7)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=7)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=8)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=8)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=8)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=8)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=8)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))))

AF_9&10&11&12[Area,AgeGroup] =
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=9)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=9)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=9)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=9)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=9)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=10)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=10)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=10)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=10)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=10)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=11)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=11)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=11)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=11)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=11)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))))+

(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=12)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=12)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=12)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=12)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=12)THEN(RCW_Imm_F[Area,AgeGroup])ELSE(0))))

AM_1&2&3&4[Area,AgeGroup] =
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=1)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=1)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=1)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=1)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=1)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=2)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=2)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=2)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=2)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=2)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=3)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=3)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=3)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=3)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=3)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=4)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=4)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=4)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=4)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=4)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))))

AM_13&14&15&16[Area,AgeGroup] =
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=13)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=13)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=13)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=13)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=13)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=14)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=14)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=14)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=14)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=14)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=15)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=15)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=15)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=15)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=15)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=16)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=16)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=16)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=16)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=16)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))))

AM_17&18&19&20[Area,AgeGroup] =
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=17)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=17)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=17)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=17)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=17)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=18)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=18)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=18)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=18)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=18)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))))+

(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=19)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=19)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=19)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=19)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=19)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=20)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=20)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=20)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=20)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=20)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))))

AM_5&6&7&8[Area,AgeGroup] =
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=5)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=5)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=5)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=5)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=5)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=6)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=6)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=6)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=6)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=6)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=7)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=7)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=7)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=7)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=7)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=8)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=8)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=8)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=8)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=8)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))))

AM_9&10&11&12[Area,AgeGroup] =
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=9)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=9)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=9)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=9)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=9)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=10)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=10)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=10)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=10)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=10)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=11)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=11)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=11)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=11)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=11)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))))+
(((IF(RCW_AgeGroup[AgeGroup]=1)AND(Area#[Area]=12)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=2)AND(Area#[Area]=12)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=3)AND(Area#[Area]=12)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=4)AND(Area#[Area]=12)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))+
(IF(RCW_AgeGroup[AgeGroup]=5)AND(Area#[Area]=12)THEN(RCW_Imm_M[Area,AgeGroup])ELSE(0))))

Area#[A1] = 1	Area#[A6] = 6	Area#[A11] = 11	Area#[A16] = 16
Area#[A2] = 2	Area#[A7] = 7	Area#[A12] = 12	Area#[A17] = 17
Area#[A3] = 3	Area#[A8] = 8	Area#[A13] = 13	Area#[A18] = 18
Area#[A4] = 4	Area#[A9] = 9	Area#[A14] = 14	Area#[A19] = 19
Area#[A5] = 5	Area#[A10] = 10	Area#[A15] = 15	Area#[A20] = 20

CavIndexDispWt = 4

CavIndexImmWt = 5

CorrDispWt = 1

Corridor[A1,A1] = 0
Corridor[A1,A2] = 1
Corridor[A1,A3] = 0.75
Corridor[A1,A4] = 1
Corridor[A1,A5] = 1
Corridor[A1,A6] = 0.5
Corridor[A1,A7] = 0.5
Corridor[A1,A8] = 0.5
Corridor[A1,A9] = 0.25
Corridor[A1,A10] = 0.25
Corridor[A1,A11] = 0.25
Corridor[A1,A12] = 0
Corridor[A1,A13] = 0
Corridor[A1,A14] = 0
Corridor[A1,A15] = 0
Corridor[A1,A16] = 0
Corridor[A1,A17] = 0
Corridor[A1,A18] = 0
Corridor[A1,A19] = 0
Corridor[A1,A20] = 0
Corridor[A2,A1] = 1
Corridor[A2,A2] = 0
Corridor[A2,A3] = 1
Corridor[A2,A4] = 0.75
Corridor[A2,A5] = 1
Corridor[A2,A6] = 0.75
Corridor[A2,A7] = 0.5
Corridor[A2,A8] = 0.25
Corridor[A2,A9] = 0.25
Corridor[A2,A10] = 0.25
Corridor[A2,A11] = 0
Corridor[A2,A12] = 0
Corridor[A2,A13] = 0
Corridor[A2,A14] = 0
Corridor[A2,A15] = 0
Corridor[A2,A16] = 0
Corridor[A2,A17] = 0
Corridor[A2,A18] = 0
Corridor[A2,A19] = 0
Corridor[A2,A20] = 0
Corridor[A3,A1] = 0.75
Corridor[A3,A2] = 1
Corridor[A3,A3] = 0
Corridor[A3,A4] = 0.25
Corridor[A3,A5] = 0.75
Corridor[A3,A6] = 1
Corridor[A3,A7] = 0.25
Corridor[A3,A8] = 0.25
Corridor[A3,A9] = 0
Corridor[A3,A10] = 0
Corridor[A3,A11] = 0
Corridor[A3,A12] = 0
Corridor[A3,A13] = 0
Corridor[A3,A14] = 0
Corridor[A3,A15] = 0
Corridor[A3,A16] = 0
Corridor[A3,A17] = 0
Corridor[A3,A18] = 0
Corridor[A3,A19] = 0
Corridor[A3,A20] = 0
Corridor[A4,A1] = 1
Corridor[A4,A2] = 0.75
Corridor[A4,A3] = 0.25
Corridor[A4,A4] = 0
Corridor[A4,A5] = 1
Corridor[A4,A6] = 0
Corridor[A4,A7] = 1
Corridor[A4,A8] = 0.75
Corridor[A4,A9] = 0.75
Corridor[A4,A10] = 0.75
Corridor[A4,A11] = 0.5
Corridor[A4,A12] = 0.25
Corridor[A4,A13] = 0
Corridor[A4,A14] = 0.25
Corridor[A4,A15] = 0
Corridor[A4,A16] = 0
Corridor[A4,A17] = 0
Corridor[A4,A18] = 0
Corridor[A4,A19] = 0
Corridor[A4,A20] = 0
Corridor[A5,A1] = 1
Corridor[A5,A2] = 1
Corridor[A5,A3] = 0.75
Corridor[A5,A4] = 1
Corridor[A5,A5] = 0
Corridor[A5,A6] = 0.25
Corridor[A5,A7] = 1
Corridor[A5,A8] = 1
Corridor[A5,A9] = 0.75
Corridor[A5,A10] = 0.75
Corridor[A5,A11] = 0.5
Corridor[A5,A12] = 0.5
Corridor[A5,A13] = 0.25
Corridor[A5,A14] = 0.25
Corridor[A5,A15] = 0
Corridor[A5,A16] = 0
Corridor[A5,A17] = 0
Corridor[A5,A18] = 0
Corridor[A5,A19] = 0
Corridor[A5,A20] = 0
Corridor[A6,A1] = 0.5
Corridor[A6,A2] = 0.75
Corridor[A6,A3] = 1
Corridor[A6,A4] = 0
Corridor[A6,A5] = 0.25
Corridor[A6,A6] = 0
Corridor[A6,A7] = 0
Corridor[A6,A8] = 0.75
Corridor[A6,A9] = 0.25
Corridor[A6,A10] = 0
Corridor[A6,A11] = 0
Corridor[A6,A12] = 0
Corridor[A6,A13] = 0
Corridor[A6,A14] = 0
Corridor[A6,A15] = 0
Corridor[A6,A16] = 0
Corridor[A6,A17] = 0
Corridor[A6,A18] = 0
Corridor[A6,A19] = 0
Corridor[A6,A20] = 0
Corridor[A7,A1] = 0.5
Corridor[A7,A2] = 0.5
Corridor[A7,A3] = 0.25
Corridor[A7,A4] = 1
Corridor[A7,A5] = 1
Corridor[A7,A6] = 0
Corridor[A7,A7] = 0
Corridor[A7,A8] = 0.75
Corridor[A7,A9] = 1
Corridor[A7,A10] = 1
Corridor[A7,A11] = 1
Corridor[A7,A12] = 0.75
Corridor[A7,A13] = 0.5
Corridor[A7,A14] = 0.5
Corridor[A7,A15] = 0.25
Corridor[A7,A16] = 0
Corridor[A7,A17] = 0
Corridor[A7,A18] = 0
Corridor[A7,A19] = 0
Corridor[A7,A20] = 0
Corridor[A8,A1] = 0.5
Corridor[A8,A2] = 0.25
Corridor[A8,A3] = 0.25
Corridor[A8,A4] = 0.75
Corridor[A8,A5] = 1
Corridor[A8,A6] = 0.75
Corridor[A8,A7] = 0.75
Corridor[A8,A8] = 0
Corridor[A8,A9] = 1
Corridor[A8,A10] = 0.75
Corridor[A8,A11] = 0.75
Corridor[A8,A12] = 0.75
Corridor[A8,A13] = 0.75
Corridor[A8,A14] = 0.5
Corridor[A8,A15] = 0.25
Corridor[A8,A16] = 0
Corridor[A8,A17] = 0
Corridor[A8,A18] = 0
Corridor[A8,A19] = 0
Corridor[A8,A20] = 0
Corridor[A9,A1] = 0.25
Corridor[A9,A2] = 0.25
Corridor[A9,A3] = 0
Corridor[A9,A4] = 0.75
Corridor[A9,A5] = 0.75
Corridor[A9,A6] = 0.25
Corridor[A9,A7] = 1
Corridor[A9,A8] = 1
Corridor[A9,A9] = 0
Corridor[A9,A10] = 1
Corridor[A9,A11] = 1
Corridor[A9,A12] = 1
Corridor[A9,A13] = 1
Corridor[A9,A14] = 0.75
Corridor[A9,A15] = 0.5
Corridor[A9,A16] = 0.25
Corridor[A9,A17] = 0
Corridor[A9,A18] = 0
Corridor[A9,A19] = 0
Corridor[A9,A20] = 0
Corridor[A10,A1] = 0.25
Corridor[A10,A2] = 0.25
Corridor[A10,A3] = 0
Corridor[A10,A4] = 0.75
Corridor[A10,A5] = 0.75
Corridor[A10,A6] = 0
Corridor[A10,A7] = 1
Corridor[A10,A8] = 0.75
Corridor[A10,A9] = 1
Corridor[A10,A10] = 0
Corridor[A10,A11] = 1
Corridor[A10,A12] = 0.75
Corridor[A10,A13] = 0.5
Corridor[A10,A14] = 0.75
Corridor[A10,A15] = 0.5
Corridor[A10,A16] = 0.25
Corridor[A10,A17] = 0
Corridor[A10,A18] = 0
Corridor[A10,A19] = 0
Corridor[A10,A20] = 0
Corridor[A11,A1] = 0.25
Corridor[A11,A2] = 0
Corridor[A11,A3] = 0
Corridor[A11,A4] = 0.5
Corridor[A11,A5] = 0.5
Corridor[A11,A6] = 0
Corridor[A11,A7] = 1
Corridor[A11,A8] = 0.75
Corridor[A11,A9] = 1
Corridor[A11,A10] = 1
Corridor[A11,A11] = 0
Corridor[A11,A12] = 1
Corridor[A11,A13] = 0.75
Corridor[A11,A14] = 1
Corridor[A11,A15] = 0.75
Corridor[A11,A16] = 0.5
Corridor[A11,A17] = 0.25
Corridor[A11,A18] = 0
Corridor[A11,A19] = 0
Corridor[A11,A20] = 0

Corridor[A12,A1] = 0
Corridor[A12,A2] = 0
Corridor[A12,A3] = 0
Corridor[A12,A4] = 0.25
Corridor[A12,A5] = 0.5
Corridor[A12,A6] = 0
Corridor[A12,A7] = 0.75
Corridor[A12,A8] = 0.75
Corridor[A12,A9] = 1
Corridor[A12,A10] = 0.75
Corridor[A12,A11] = 1
Corridor[A12,A12] = 0
Corridor[A12,A13] = 1
Corridor[A12,A14] = 1
Corridor[A12,A15] = 1
Corridor[A12,A16] = 0.75
Corridor[A12,A17] = 0.5
Corridor[A12,A18] = 0.25
Corridor[A12,A19] = 0
Corridor[A12,A20] = 0
Corridor[A13,A1] = 0
Corridor[A13,A2] = 0
Corridor[A13,A3] = 0
Corridor[A13,A4] = 0
Corridor[A13,A5] = 0.25
Corridor[A13,A6] = 0
Corridor[A13,A7] = 0.5
Corridor[A13,A8] = 0.75
Corridor[A13,A9] = 1
Corridor[A13,A10] = 0.5
Corridor[A13,A11] = 0.75
Corridor[A13,A12] = 1
Corridor[A13,A13] = 0
Corridor[A13,A14] = 0.75
Corridor[A13,A15] = 0.5
Corridor[A13,A16] = 0.25
Corridor[A13,A17] = 0
Corridor[A13,A18] = 0
Corridor[A13,A19] = 0
Corridor[A13,A20] = 0
Corridor[A14,A1] = 0
Corridor[A14,A2] = 0
Corridor[A14,A3] = 0
Corridor[A14,A4] = 0.25
Corridor[A14,A5] = 0.25
Corridor[A14,A6] = 0
Corridor[A14,A7] = 0.5
Corridor[A14,A8] = 0.5
Corridor[A14,A9] = 0.75
Corridor[A14,A10] = 0.75
Corridor[A14,A11] = 1
Corridor[A14,A12] = 1
Corridor[A14,A13] = 0.75
Corridor[A14,A14] = 0
Corridor[A14,A15] = 1
Corridor[A14,A16] = 1
Corridor[A14,A17] = 0.5
Corridor[A14,A18] = 0.25
Corridor[A14,A19] = 0
Corridor[A14,A20] = 0
Corridor[A15,A1] = 0
Corridor[A15,A2] = 0
Corridor[A15,A3] = 0
Corridor[A15,A4] = 0
Corridor[A15,A5] = 0
Corridor[A15,A6] = 0
Corridor[A15,A7] = 0.25
Corridor[A15,A8] = 0.25
Corridor[A15,A9] = 0.5
Corridor[A15,A10] = 0.5
Corridor[A15,A11] = 0.75
Corridor[A15,A12] = 1
Corridor[A15,A13] = 0.5
Corridor[A15,A14] = 1
Corridor[A15,A15] = 0
Corridor[A15,A16] = 1
Corridor[A15,A17] = 0.75
Corridor[A15,A18] = 0.5
Corridor[A15,A19] = 0.25
Corridor[A15,A20] = 0
Corridor[A16,A1] = 0
Corridor[A16,A2] = 0
Corridor[A16,A3] = 0
Corridor[A16,A4] = 0
Corridor[A16,A5] = 0
Corridor[A16,A6] = 0
Corridor[A16,A7] = 0
Corridor[A16,A8] = 0
Corridor[A16,A9] = 0.25
Corridor[A16,A10] = 0.25
Corridor[A16,A11] = 0.5
Corridor[A16,A12] = 0.75
Corridor[A16,A13] = 0.25
Corridor[A16,A14] = 1
Corridor[A16,A15] = 1
Corridor[A16,A16] = 0
Corridor[A16,A17] = 1
Corridor[A16,A18] = 1
Corridor[A16,A19] = 0.5
Corridor[A16,A20] = 0
Corridor[A17,A1] = 0
Corridor[A17,A2] = 0
Corridor[A17,A3] = 0
Corridor[A17,A4] = 0
Corridor[A17,A5] = 0
Corridor[A17,A6] = 0
Corridor[A17,A7] = 0
Corridor[A17,A8] = 0
Corridor[A17,A9] = 0
Corridor[A17,A10] = 0
Corridor[A17,A11] = 0.25
Corridor[A17,A12] = 0.5
Corridor[A17,A13] = 0
Corridor[A17,A14] = 0.5
Corridor[A17,A15] = 0.75
Corridor[A17,A16] = 1
Corridor[A17,A17] = 0
Corridor[A17,A18] = 1
Corridor[A17,A19] = 0.75
Corridor[A17,A20] = 0.25
Corridor[A18,A1] = 0
Corridor[A18,A2] = 0
Corridor[A18,A3] = 0
Corridor[A18,A4] = 0
Corridor[A18,A5] = 0
Corridor[A18,A6] = 0
Corridor[A18,A7] = 0
Corridor[A18,A8] = 0
Corridor[A18,A9] = 0
Corridor[A18,A10] = 0
Corridor[A18,A11] = 0
Corridor[A18,A12] = 0.25
Corridor[A18,A13] = 0
Corridor[A18,A14] = 0.25
Corridor[A18,A15] = 0.5
Corridor[A18,A16] = 1
Corridor[A18,A17] = 1
Corridor[A18,A18] = 0
Corridor[A18,A19] = 1
Corridor[A18,A20] = 0.5
Corridor[A19,A1] = 0
Corridor[A19,A2] = 0
Corridor[A19,A3] = 0
Corridor[A19,A4] = 0
Corridor[A19,A5] = 0
Corridor[A19,A6] = 0
Corridor[A19,A7] = 0
Corridor[A19,A8] = 0
Corridor[A19,A9] = 0
Corridor[A19,A10] = 0
Corridor[A19,A11] = 0
Corridor[A19,A12] = 0
Corridor[A19,A13] = 0
Corridor[A19,A14] = 0
Corridor[A19,A15] = 0.25
Corridor[A19,A16] = 0.5
Corridor[A19,A17] = 0.75
Corridor[A19,A18] = 1
Corridor[A19,A19] = 0
Corridor[A19,A20] = 1
Corridor[A20,A1] = 0
Corridor[A20,A2] = 0
Corridor[A20,A3] = 0
Corridor[A20,A4] = 0
Corridor[A20,A5] = 0
Corridor[A20,A6] = 0
Corridor[A20,A7] = 0
Corridor[A20,A8] = 0
Corridor[A20,A9] = 0
Corridor[A20,A10] = 0
Corridor[A20,A11] = 0
Corridor[A20,A12] = 0
Corridor[A20,A13] = 0
Corridor[A20,A14] = 0
Corridor[A20,A15] = 0
Corridor[A20,A16] = 0
Corridor[A20,A17] = 0.25
Corridor[A20,A18] = 0.5
Corridor[A20,A19] = 1
Corridor[A20,A20] = 0

CorridorDispIndex[Area] = ARRAYSUM(Corridor[Area,*])/10

DispPotTotWt = CorrDispWt+CavIndexDispWt+ForIndexDispWt

DispSwitch = 1

ForIndexDispWt = 3

ForIndexImmWt = 2

ImmPotTotWt = CavIndexImmWt+ForIndexImmWt

RCWFemaleMortAdd = 1.1

RCWMortMag = 1.0

RCW_AdultLossF[Area] = ARRAYSUM(RCW_DispF[Area,*])+ARRAYSUM(RCW_MortF[Area,*])

RCW_AdultLossM[Area] = ARRAYSUM(RCW_DispM[Area,*])+ARRAYSUM(RCW_MortM[Area,*])

RCW_AgeGroup[Age1] = 1
RCW_AgeGroup[Age2] = 2
RCW_AgeGroup[Age3] = 3
RCW_AgeGroup[Age4] = 4
RCW_AgeGroup[Age5plus] = 5

RCW_AreaF[Area] = ARRAYSUM(RCW_AgeF[Area,*])

RCW_AreaHelpers[Area] = IF(RCW_BreedingM[Area]>=1)THEN(RCW_AreaM[Area]-1)ELSE(0)

RCW_AreaM[Area] = ARRAYSUM(RCW_AgeM[Area,*])

RCW_AreaPop[Area] = RCW_AreaF[Area]+RCW_AreaM[Area]

RCW_AreaTotF[Area] = RCW_FledglingF[Area]+RCW_AreaF[Area]

RCW_AreaTotM[Area] = RCW_FledglingF[Area]+RCW_AreaM[Area]

RCW_BreedingF[Area] = IF(RCW_AgeF[Area,Age5plus]>=1)THEN(5)ELSE(
IF(RCW_AgeF[Area,Age4]>=1)THEN(4)ELSE(
IF(RCW_AgeF[Area,Age3]>=1)THEN(3)ELSE(
IF(RCW_AgeF[Area,Age2]>=1)THEN(2)ELSE(
IF(RCW_AgeF[Area,Age1]>=1)THEN(1)ELSE(0)))))

RCW_BreedingM[Area] = IF(RCW_AgeM[Area,Age5plus]>=1)THEN(5)ELSE(
IF(RCW_AgeM[Area,Age4]>=1)THEN(4)ELSE(
IF(RCW_AgeM[Area,Age3]>=1)THEN(3)ELSE(
IF(RCW_AgeM[Area,Age2]>=1)THEN(2)ELSE(
IF(RCW_AgeM[Area,Age1]>=1)THEN(1)ELSE(0)))))

RCW_BreedingPair[Area] =
IF(RCW_BreedingF[Area]>=1)AND(RCW_BreedingM[Area]>=1)THEN(RCW_BreedingF[Area]+
RCW_BreedingM[Area])ELSE(0)

RCW_BreedMImmEffectF = 0.7

RCW_BreedMImmEffectM = 0.8

RCW_DispDecisionF[Area] =
IF(RCW_BreedingM[Area]>=1)THEN(RCW_DispPotential[Area]*RCW_BreedMImmEffectF)ELSE
(RCW_DispPotential[Area])

RCW_DispDecisionM[Area] =
IF(RCW_BreedingM[Area]>=1)THEN(RCW_DispPotential[Area])ELSE(RCW_DispPotential[Area]*
RCW_BreedMImmEffectM)

RCW_DispF_1[Area,AgeGroup] = RCW_DispF[Area,Age1]*MAX(
(RCW_ImmDecisionF[A1]*Corridor[A1, Area]), (RCW_ImmDecisionF[A2]*Corridor[A2, Area]),
(RCW_ImmDecisionF[A3]*Corridor[A3, Area]),(RCW_ImmDecisionF[A4]*Corridor[A4, Area]),
(RCW_ImmDecisionF[A5]*Corridor[A5, Area]),(RCW_ImmDecisionF[A6]*Corridor[A6, Area]),

(RCW_ImmDecisionF[A7]*Corridor[A7, Area]),(RCW_ImmDecisionF[A8]*Corridor[A8, Area]),
(RCW_ImmDecisionF[A9]*Corridor[A9, Area]),(RCW_ImmDecisionF[A10]*Corridor[A10, Area]),
(RCW_ImmDecisionF[A11]*Corridor[A11, Area]),(RCW_ImmDecisionF[A12]*Corridor[A12, Area]),
(RCW_ImmDecisionF[A13]*Corridor[A13, Area]),(RCW_ImmDecisionF[A14]*Corridor[A14, Area]),
(RCW_ImmDecisionF[A15]*Corridor[A15, Area]),(RCW_ImmDecisionF[A16]*Corridor[A16, Area]),
(RCW_ImmDecisionF[A17]*Corridor[A17, Area]),(RCW_ImmDecisionF[A18]*Corridor[A18, Area]),
(RCW_ImmDecisionF[A19]*Corridor[A19, Area]),(RCW_ImmDecisionF[A20]*Corridor[A20, Area]))

RCW_DispF_2[Area,AgeGroup] = RCW_DispF[Area,Age2]*MAX(
(RCW_ImmDecisionF[A1]*Corridor[A1, Area]),(RCW_ImmDecisionF[A2]*Corridor[A2, Area]),
(RCW_ImmDecisionF[A3]*Corridor[A3, Area]),(RCW_ImmDecisionF[A4]*Corridor[A4, Area]),
(RCW_ImmDecisionF[A5]*Corridor[A5, Area]),(RCW_ImmDecisionF[A6]*Corridor[A6, Area]),
(RCW_ImmDecisionF[A7]*Corridor[A7, Area]),(RCW_ImmDecisionF[A8]*Corridor[A8, Area]),
(RCW_ImmDecisionF[A9]*Corridor[A9, Area]),(RCW_ImmDecisionF[A10]*Corridor[A10, Area]),
(RCW_ImmDecisionF[A11]*Corridor[A11, Area]),(RCW_ImmDecisionF[A12]*Corridor[A12, Area]),
(RCW_ImmDecisionF[A13]*Corridor[A13, Area]),(RCW_ImmDecisionF[A14]*Corridor[A14, Area]),
(RCW_ImmDecisionF[A15]*Corridor[A15, Area]),(RCW_ImmDecisionF[A16]*Corridor[A16, Area]),
(RCW_ImmDecisionF[A17]*Corridor[A17, Area]),(RCW_ImmDecisionF[A18]*Corridor[A18, Area]),
(RCW_ImmDecisionF[A19]*Corridor[A19, Area]),(RCW_ImmDecisionF[A20]*Corridor[A20, Area]))

RCW_DispF_3[Area,AgeGroup] = RCW_DispF[Area,Age3]*MAX(
(RCW_ImmDecisionF[A1]*Corridor[A1, Area]),(RCW_ImmDecisionF[A2]*Corridor[A2, Area]),
(RCW_ImmDecisionF[A3]*Corridor[A3, Area]),(RCW_ImmDecisionF[A4]*Corridor[A4, Area]),
(RCW_ImmDecisionF[A5]*Corridor[A5, Area]),(RCW_ImmDecisionF[A6]*Corridor[A6, Area]),
(RCW_ImmDecisionF[A7]*Corridor[A7, Area]),(RCW_ImmDecisionF[A8]*Corridor[A8, Area]),
(RCW_ImmDecisionF[A9]*Corridor[A9, Area]),(RCW_ImmDecisionF[A10]*Corridor[A10, Area]),
(RCW_ImmDecisionF[A11]*Corridor[A11, Area]),(RCW_ImmDecisionF[A12]*Corridor[A12, Area]),
(RCW_ImmDecisionF[A13]*Corridor[A13, Area]),(RCW_ImmDecisionF[A14]*Corridor[A14, Area]),
(RCW_ImmDecisionF[A15]*Corridor[A15, Area]),(RCW_ImmDecisionF[A16]*Corridor[A16, Area]),
(RCW_ImmDecisionF[A17]*Corridor[A17, Area]),(RCW_ImmDecisionF[A18]*Corridor[A18, Area]),
(RCW_ImmDecisionF[A19]*Corridor[A19, Area]),(RCW_ImmDecisionF[A20]*Corridor[A20, Area]))

RCW_DispF_4[Area,AgeGroup] = RCW_DispF[Area,Age4]*MAX(
(RCW_ImmDecisionF[A1]*Corridor[A1, Area]),(RCW_ImmDecisionF[A2]*Corridor[A2, Area]),
(RCW_ImmDecisionF[A3]*Corridor[A3, Area]),(RCW_ImmDecisionF[A4]*Corridor[A4, Area]),
(RCW_ImmDecisionF[A5]*Corridor[A5, Area]),(RCW_ImmDecisionF[A6]*Corridor[A6, Area]),
(RCW_ImmDecisionF[A7]*Corridor[A7, Area]),(RCW_ImmDecisionF[A8]*Corridor[A8, Area]),
(RCW_ImmDecisionF[A9]*Corridor[A9, Area]),(RCW_ImmDecisionF[A10]*Corridor[A10, Area]),
(RCW_ImmDecisionF[A11]*Corridor[A11, Area]),(RCW_ImmDecisionF[A12]*Corridor[A12, Area]),
(RCW_ImmDecisionF[A13]*Corridor[A13, Area]),(RCW_ImmDecisionF[A14]*Corridor[A14, Area]),
(RCW_ImmDecisionF[A15]*Corridor[A15, Area]),(RCW_ImmDecisionF[A16]*Corridor[A16, Area]),
(RCW_ImmDecisionF[A17]*Corridor[A17, Area]), (RCW_ImmDecisionF[A18]*Corridor[A18, Area]),
(RCW_ImmDecisionF[A19]*Corridor[A19, Area]),(RCW_ImmDecisionF[A20]*Corridor[A20, Area]))

RCW_DispM_1[Area,AgeGroup] = RCW_DispM[Area,Age1]*MAX(
(RCW_ImmDecisionM[A1]*Corridor[A1, Area]),(RCW_ImmDecisionM[A2]*Corridor[A2, Area]),
(RCW_ImmDecisionM[A3]*Corridor[A3, Area]),(RCW_ImmDecisionM[A4]*Corridor[A4, Area]),
(RCW_ImmDecisionM[A5]*Corridor[A5, Area]),(RCW_ImmDecisionM[A6]*Corridor[A6, Area]),
(RCW_ImmDecisionM[A7]*Corridor[A7, Area]),(RCW_ImmDecisionM[A8]*Corridor[A8, Area]),
(RCW_ImmDecisionM[A9]*Corridor[A9, Area]),(RCW_ImmDecisionM[A10]*Corridor[A10, Area]),
(RCW_ImmDecisionM[A11]*Corridor[A11, Area]),(RCW_ImmDecisionM[A12]*Corridor[A12, Area]),
(RCW_ImmDecisionM[A13]*Corridor[A13, Area]),(RCW_ImmDecisionM[A14]*Corridor[A14, Area]),
(RCW_ImmDecisionM[A15]*Corridor[A15, Area]),(RCW_ImmDecisionM[A16]*Corridor[A16, Area]),
(RCW_ImmDecisionM[A17]*Corridor[A17, Area]),(RCW_ImmDecisionM[A18]*Corridor[A18, Area]),
(RCW_ImmDecisionM[A19]*Corridor[A19, Area]),(RCW_ImmDecisionM[A20]*Corridor[A20, Area]))

RCW_DispM_2[Area,AgeGroup] = RCW_DispM[Area,Age2]*MAX(
(RCW_ImmDecisionM[A1]*Corridor[A1, Area]),(RCW_ImmDecisionM[A2]*Corridor[A2, Area]),
(RCW_ImmDecisionM[A3]*Corridor[A3, Area]),(RCW_ImmDecisionM[A4]*Corridor[A4, Area]),
(RCW_ImmDecisionM[A5]*Corridor[A5, Area]),(RCW_ImmDecisionM[A6]*Corridor[A6, Area]),
(RCW_ImmDecisionM[A7]*Corridor[A7, Area]),(RCW_ImmDecisionM[A8]*Corridor[A8, Area]),
(RCW_ImmDecisionM[A9]*Corridor[A9, Area]),(RCW_ImmDecisionM[A10]*Corridor[A10, Area]),
(RCW_ImmDecisionM[A11]*Corridor[A11, Area]),(RCW_ImmDecisionM[A12]*Corridor[A12, Area]),
(RCW_ImmDecisionM[A13]*Corridor[A13, Area]),(RCW_ImmDecisionM[A14]*Corridor[A14, Area]),
(RCW_ImmDecisionM[A15]*Corridor[A15, Area]),(RCW_ImmDecisionM[A16]*Corridor[A16, Area]),
(RCW_ImmDecisionM[A17]*Corridor[A17, Area]),(RCW_ImmDecisionM[A18]*Corridor[A18, Area]),
(RCW_ImmDecisionM[A19]*Corridor[A19, Area]),(RCW_ImmDecisionM[A20]*Corridor[A20, Area]))

RCW_DispM_3[Area,AgeGroup] = RCW_DispM[Area,Age3]*MAX(
(RCW_ImmDecisionM[A1]*Corridor[A1, Area]),(RCW_ImmDecisionM[A2]*Corridor[A2, Area]),
(RCW_ImmDecisionM[A3]*Corridor[A3, Area]),(RCW_ImmDecisionM[A4]*Corridor[A4, Area]),
(RCW_ImmDecisionM[A5]*Corridor[A5, Area]),(RCW_ImmDecisionM[A6]*Corridor[A6, Area]),
(RCW_ImmDecisionM[A7]*Corridor[A7, Area]),(RCW_ImmDecisionM[A8]*Corridor[A8, Area]),
(RCW_ImmDecisionM[A9]*Corridor[A9, Area]), (RCW_ImmDecisionM[A10]*Corridor[A10, Area]),
(RCW_ImmDecisionM[A11]*Corridor[A11, Area]),(RCW_ImmDecisionM[A12]*Corridor[A12, Area]),
(RCW_ImmDecisionM[A13]*Corridor[A13, Area]),(RCW_ImmDecisionM[A14]*Corridor[A14, Area]),
(RCW_ImmDecisionM[A15]*Corridor[A15, Area]),(RCW_ImmDecisionM[A16]*Corridor[A16, Area]),
(RCW_ImmDecisionM[A17]*Corridor[A17, Area]),(RCW_ImmDecisionM[A18]*Corridor[A18, Area]),
(RCW_ImmDecisionM[A19]*Corridor[A19, Area]),(RCW_ImmDecisionM[A20]*Corridor[A20, Area]))

RCW_DispM_4[Area,AgeGroup] = RCW_DispM[Area,Age4]*MAX(
(RCW_ImmDecisionM[A1]*Corridor[A1, Area]),(RCW_ImmDecisionM[A2]*Corridor[A2, Area]),
(RCW_ImmDecisionM[A3]*Corridor[A3, Area]),(RCW_ImmDecisionM[A4]*Corridor[A4, Area]),
(RCW_ImmDecisionM[A5]*Corridor[A5, Area]),(RCW_ImmDecisionM[A6]*Corridor[A6, Area]),
(RCW_ImmDecisionM[A7]*Corridor[A7, Area]),(RCW_ImmDecisionM[A8]*Corridor[A8, Area]),
(RCW_ImmDecisionM[A9]*Corridor[A9, Area]),(RCW_ImmDecisionM[A10]*Corridor[A10, Area]),
(RCW_ImmDecisionM[A11]*Corridor[A11, Area]),(RCW_ImmDecisionM[A12]*Corridor[A12, Area]),
(RCW_ImmDecisionM[A13]*Corridor[A13, Area]),(RCW_ImmDecisionM[A14]*Corridor[A14, Area]),
(RCW_ImmDecisionM[A15]*Corridor[A15, Area]),(RCW_ImmDecisionM[A16]*Corridor[A16, Area]),
(RCW_ImmDecisionM[A17]*Corridor[A17, Area]),(RCW_ImmDecisionM[A18]*Corridor[A18, Area]),
(RCW_ImmDecisionM[A19]*Corridor[A19, Area]),(RCW_ImmDecisionM[A20]*Corridor[A20, Area]))

RCW_DispPotential[Area] =
IF(ForagingIndex[Area]<0.4)OR(CorridorDispIndex[Area]<=0.1)OR(CavIndex[Area]<=0.2)THEN(1)ELS
E(((1-CavIndexDispWt*CavIndex[Area])+CorrDispWt*CorridorDispIndex[Area]+(1-
ForIndexDispWt*ForagingIndex[Area]))/DispPotTotWt)

RCW_FArea[A1] = 0	RCW_FArea[A6] = 0	RCW_FArea[A11] = 0	RCW_FArea[A16] = 0
RCW_FArea[A2] = 0	RCW_FArea[A7] = 0	RCW_FArea[A12] = 0	RCW_FArea[A17] = 0
RCW_FArea[A3] = 1	RCW_FArea[A8] = 0	RCW_FArea[A13] = 0	RCW_FArea[A18] = 0
RCW_FArea[A4] = 0	RCW_FArea[A9] = 0	RCW_FArea[A14] = 1	RCW_FArea[A19] = 0
RCW_FArea[A5] = 0	RCW_FArea[A10] = 1	RCW_FArea[A15] = 0	RCW_FArea[A20] = 0

RCW_FDispF[Area] = RCW_FledgDispF[Area]*MAX(
(RCW_ImmDecisionF[A1]*Corridor[A1, Area]),(RCW_ImmDecisionF[A2]*Corridor[A2, Area]),
(RCW_ImmDecisionF[A3]*Corridor[A3, Area]),(RCW_ImmDecisionF[A4]*Corridor[A4, Area]),
(RCW_ImmDecisionF[A5]*Corridor[A5, Area]),(RCW_ImmDecisionF[A6]*Corridor[A6, Area]),
(RCW_ImmDecisionF[A7]*Corridor[A7, Area]),(RCW_ImmDecisionF[A8]*Corridor[A8, Area]),
(RCW_ImmDecisionF[A9]*Corridor[A9, Area]),(RCW_ImmDecisionF[A10]*Corridor[A10, Area]),
(RCW_ImmDecisionF[A11]*Corridor[A11, Area]),(RCW_ImmDecisionF[A12]*Corridor[A12, Area]),
(RCW_ImmDecisionF[A13]*Corridor[A13, Area]),(RCW_ImmDecisionF[A14]*Corridor[A14, Area]),
(RCW_ImmDecisionF[A15]*Corridor[A15, Area]),(RCW_ImmDecisionF[A16]*Corridor[A16, Area]),

(RCW_ImmDecisionF[A17]*Corridor[A17, Area]),(RCW_ImmDecisionF[A18]*Corridor[A18, Area]),
(RCW_ImmDecisionF[A19]*Corridor[A19, Area]),(RCW_ImmDecisionF[A20]*Corridor[A20, Area]))

RCW_FDispM[Area] = RCW_FledgDispM[Area]*MAX(
(RCW_ImmDecisionM[A1]*Corridor[A1, Area]),(RCW_ImmDecisionM[A2]*Corridor[A2, Area]),
(RCW_ImmDecisionM[A3]*Corridor[A3, Area]),(RCW_ImmDecisionM[A4]*Corridor[A4, Area]),
(RCW_ImmDecisionM[A5]*Corridor[A5, Area]),(RCW_ImmDecisionM[A6]*Corridor[A6, Area]),
(RCW_ImmDecisionM[A7]*Corridor[A7, Area]),(RCW_ImmDecisionM[A8]*Corridor[A8, Area]),
(RCW_ImmDecisionM[A9]*Corridor[A9, Area]),(RCW_ImmDecisionM[A10]*Corridor[A10, Area]),
(RCW_ImmDecisionM[A11]*Corridor[A11, Area]),(RCW_ImmDecisionM[A12]*Corridor[A12, Area]),
(RCW_ImmDecisionM[A13]*Corridor[A13, Area]),(RCW_ImmDecisionM[A14]*Corridor[A14, Area]),
(RCW_ImmDecisionM[A15]*Corridor[A15, Area]),(RCW_ImmDecisionM[A16]*Corridor[A16, Area]),
(RCW_ImmDecisionM[A17]*Corridor[A17, Area]),(RCW_ImmDecisionM[A18]*Corridor[A18, Area]),
(RCW_ImmDecisionM[A19]*Corridor[A19, Area]),(RCW_ImmDecisionM[A20]*Corridor[A20, Area]))

RCW_FirstTrans[A1] = 0
RCW_FirstTrans[A2] = 0
RCW_FirstTrans[A3] = 5
RCW_FirstTrans[A4] = 0
RCW_FirstTrans[A5] = 0
RCW_FirstTrans[A6] = 0
RCW_FirstTrans[A7] = 0
RCW_FirstTrans[A8] = 0
RCW_FirstTrans[A9] = 0
RCW_FirstTrans[A10] = 10
RCW_FirstTrans[A11] = 0
RCW_FirstTrans[A12] = 0
RCW_FirstTrans[A13] = 0
RCW_FirstTrans[A14] = 15
RCW_FirstTrans[A15] = 0
RCW_FirstTrans[A16] = 0
RCW_FirstTrans[A17] = 0
RCW_FirstTrans[A18] = 0
RCW_FirstTrans[A19] = 0
RCW_FirstTrans[A20] = 0

RCW_FTrans[Area,AgeGroup] =
RCW_FArea[Area]*(RCW_TransF1[AgeGroup]*RCW_Trans1FYN+RCW_TransF2[AgeGroup]*
RCW_Trans2FYN)

RCW_GainAreaF[Area] = RCW_MatureF[Area,Age1]+ARRAYSUM(RCW_ImmF[Area,*])

RCW_GainAreaM[Area] = RCW_MatureM[Area,Age1]+ARRAYSUM(RCW_ImmM[Area,*])

RCW_Imm1F[Area,AgeGroup] = RCW_Imm1F1[Area,AgeGroup]+RCW_Imm1F2[Area,AgeGroup]

RCW_Imm1F1[Area,AgeGroup] = (RCW_AgeGroup[AgeGroup]=1) AND (
(IF ((RCW_FledgDispF[A1]*RCW_ImmDecisionF[Area]*Corridor[A1, Area]) = RCW_FDispF[A1])
THEN (RCW_FledgDispF[A1]) ELSE(0)) +
(IF ((RCW_FledgDispF[A2]*RCW_ImmDecisionF[Area]*Corridor[A2, Area]) = RCW_FDispF[A2])
THEN (RCW_FledgDispF[A2]) ELSE(0)) +
(IF ((RCW_FledgDispF[A3]*RCW_ImmDecisionF[Area]*Corridor[A3, Area]) = RCW_FDispF[A3])
THEN (RCW_FledgDispF[A3]) ELSE(0)) +
(IF ((RCW_FledgDispF[A4]*RCW_ImmDecisionF[Area]*Corridor[A4, Area]) = RCW_FDispF[A4])
THEN (RCW_FledgDispF[A4]) ELSE(0)) +
(IF ((RCW_FledgDispF[A5]*RCW_ImmDecisionF[Area]*Corridor[A5, Area]) = RCW_FDispF[A5])
THEN (RCW_FledgDispF[A5]) ELSE(0)) +
(IF ((RCW_FledgDispF[A6]*RCW_ImmDecisionF[Area]*Corridor[A6, Area]) = RCW_FDispF[A6])
THEN (RCW_FledgDispF[A6]) ELSE(0)) +
(IF ((RCW_FledgDispF[A7]*RCW_ImmDecisionF[Area]*Corridor[A7, Area]) = RCW_FDispF[A7])
THEN (RCW_FledgDispF[A7]) ELSE(0)) +
(IF ((RCW_FledgDispF[A8]*RCW_ImmDecisionF[Area]*Corridor[A8, Area]) = RCW_FDispF[A8])
THEN (RCW_FledgDispF[A8]) ELSE(0)) +
(IF ((RCW_FledgDispF[A9]*RCW_ImmDecisionF[Area]*Corridor[A9, Area]) = RCW_FDispF[A9])
THEN (RCW_FledgDispF[A9]) ELSE(0)) +
(IF ((RCW_FledgDispF[A10]*RCW_ImmDecisionF[Area]*Corridor[A10, Area]) = RCW_FDispF[A10])
THEN (RCW_FledgDispF[A10]) ELSE(0)))

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RCW_Imm1F2[Area,AgeGroup] = (RCW_AgeGroup[AgeGroup]=1) AND   (
(IF ( (RCW_FledgDispF[A11]*RCW_ImmDecisionF[Area]*Corridor[A11, Area]) = RCW_FDispF[A11])
        THEN (RCW_FledgDispF[A11])   ELSE(0)) +
(IF ( (RCW_FledgDispF[A12]*RCW_ImmDecisionF[Area]*Corridor[A12, Area]) = RCW_FDispF[A12])
        THEN (RCW_FledgDispF[A12])   ELSE(0)) +
(IF ( (RCW_FledgDispF[A13]*RCW_ImmDecisionF[Area]*Corridor[A13, Area]) = RCW_FDispF[A13])
        THEN (RCW_FledgDispF[A13])   ELSE(0)) +
(IF ( (RCW_FledgDispF[A14]*RCW_ImmDecisionF[Area]*Corridor[A14, Area]) = RCW_FDispF[A14])
        THEN (RCW_FledgDispF[A14])   ELSE(0)) +
(IF ( (RCW_FledgDispF[A15]*RCW_ImmDecisionF[Area]*Corridor[A15, Area]) = RCW_FDispF[A15])
        THEN (RCW_FledgDispF[A15])   ELSE(0)) +
(IF ( (RCW_FledgDispF[A16]*RCW_ImmDecisionF[Area]*Corridor[A16, Area]) = RCW_FDispF[A16])
        THEN (RCW_FledgDispF[A16])   ELSE(0)) +
(IF ( (RCW_FledgDispF[A17]*RCW_ImmDecisionF[Area]*Corridor[A17, Area]) = RCW_FDispF[A17])
        THEN (RCW_FledgDispF[A17])   ELSE(0)) +
(IF ( (RCW_FledgDispF[A18]*RCW_ImmDecisionF[Area]*Corridor[A18, Area]) = RCW_FDispF[A18])
        THEN (RCW_FledgDispF[A18])   ELSE(0)) +
(IF ( (RCW_FledgDispF[A19]*RCW_ImmDecisionF[Area]*Corridor[A19, Area]) = RCW_FDispF[A19])
        THEN (RCW_FledgDispF[A19])   ELSE(0)) +
(IF ( (RCW_FledgDispF[A20]*RCW_ImmDecisionF[Area]*Corridor[A20, Area]) = RCW_FDispF[A20])
        THEN (RCW_FledgDispF[A20])   ELSE(0)))

RCW_Imm1M[Area,AgeGroup] = RCW_Imm1M1[Area,AgeGroup]+RCW_Imm1M2[Area,AgeGroup]

RCW_Imm1M1[Area,AgeGroup] = (RCW_AgeGroup[AgeGroup]=1) AND   (
(IF ( (RCW_FledgDispM[A1]*RCW_ImmDecisionM[Area]*Corridor[A1, Area]) = RCW_FDispM[A1])
        THEN   (RCW_FledgDispM[A1])  ELSE(0)) +
(IF ( (RCW_FledgDispM[A2]*RCW_ImmDecisionM[Area]*Corridor[A2, Area]) = RCW_FDispM[A2])
        THEN (RCW_FledgDispM[A2])   ELSE(0)) +
(IF ( (RCW_FledgDispM[A3]*RCW_ImmDecisionM[Area]*Corridor[A3, Area]) = RCW_FDispM[A3])
        THEN (RCW_FledgDispM[A3])   ELSE(0)) +
(IF ( (RCW_FledgDispM[A4]*RCW_ImmDecisionM[Area]*Corridor[A4, Area]) = RCW_FDispM[A4])
        THEN (RCW_FledgDispM[A4])   ELSE(0)) +
(IF ( (RCW_FledgDispM[A5]*RCW_ImmDecisionM[Area]*Corridor[A5, Area]) = RCW_FDispM[A5])
        THEN (RCW_FledgDispM[A5])   ELSE(0)) +
(IF ( (RCW_FledgDispM[A6]*RCW_ImmDecisionM[Area]*Corridor[A6, Area]) = RCW_FDispM[A6])
        THEN (RCW_FledgDispM[A6])   ELSE(0)) +
(IF ( (RCW_FledgDispM[A7]*RCW_ImmDecisionM[Area]*Corridor[A7, Area]) = RCW_FDispM[A7])
        THEN (RCW_FledgDispM[A7])   ELSE(0)) +
(IF ( (RCW_FledgDispM[A8]*RCW_ImmDecisionM[Area]*Corridor[A8, Area]) = RCW_FDispM[A8])
        THEN (RCW_FledgDispM[A8])   ELSE(0)) +
(IF ( (RCW_FledgDispM[A9]*RCW_ImmDecisionM[Area]*Corridor[A9, Area]) = RCW_FDispM[A9])
        THEN (RCW_FledgDispM[A9])   ELSE(0)) +
(IF ( (RCW_FledgDispM[A10]*RCW_ImmDecisionM[Area]*Corridor[A10, Area]) = RCW_FDispM[A10])
        THEN (RCW_FledgDispM[A10])  ELSE(0)))

RCW_Imm1M2[Area,AgeGroup] = (RCW_AgeGroup[AgeGroup]=1) AND   (
(IF ( (RCW_FledgDispM[A11]*RCW_ImmDecisionM[Area]*Corridor[A11, Area]) =
RCW_FDispM[A11])      THEN (RCW_FledgDispM[A11])        ELSE(0)) +
(IF ( (RCW_FledgDispM[A12]*RCW_ImmDecisionM[Area]*Corridor[A12, Area]) =
RCW_FDispM[A12])      THEN (RCW_FledgDispM[A12])        ELSE(0)) +
(IF ( (RCW_FledgDispM[A13]*RCW_ImmDecisionM[Area]*Corridor[A13, Area]) =
RCW_FDispM[A13])      THEN (RCW_FledgDispM[A13])        ELSE(0)) +
(IF ( (RCW_FledgDispM[A14]*RCW_ImmDecisionM[Area]*Corridor[A14, Area]) =
RCW_FDispM[A14])      THEN (RCW_FledgDispM[A14])        ELSE(0)) +
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(IF ((RCW_FledgDispM[A15]*RCW_ImmDecisionM[Area]*Corridor[A15, Area]) = RCW_FDispM[A15]) THEN (RCW_FledgDispM[A15])ELSE(0)) +
(IF ((RCW_FledgDispM[A16]*RCW_ImmDecisionM[Area]*Corridor[A16, Area]) = RCW_FDispM[A16]) THEN (RCW_FledgDispM[A16])ELSE(0)) +
(IF ((RCW_FledgDispM[A17]*RCW_ImmDecisionM[Area]*Corridor[A17, Area]) = RCW_FDispM[A17]) THEN (RCW_FledgDispM[A17]) ELSE(0)) +
(IF ((RCW_FledgDispM[A18]*RCW_ImmDecisionM[Area]*Corridor[A18, Area]) = RCW_FDispM[A18]) THEN (RCW_FledgDispM[A18])ELSE(0)) +
(IF ((RCW_FledgDispM[A19]*RCW_ImmDecisionM[Area]*Corridor[A19, Area]) = RCW_FDispM[A19]) THEN (RCW_FledgDispM[A19])ELSE(0)) +
(IF ((RCW_FledgDispM[A20]*RCW_ImmDecisionM[Area]*Corridor[A20, Area]) = RCW_FDispM[A20]) THEN (RCW_FledgDispM[A20]) ELSE(0)))

RCW_Imm2F[Area,AgeGroup] = RCW_Imm2F1[Area,AgeGroup]+RCW_Imm2F2[Area,AgeGroup]

RCW_Imm2F1[Area,AgeGroup] = (RCW_AgeGroup[AgeGroup]=2) AND (
(IF ((RCW_DispF[A1,Age1]*RCW_ImmDecisionF[Area]*Corridor[A1, Area]) = RCW_DispF_1[A1,Age1]) THEN (RCW_DispF[A1,Age1]) ELSE(0)) +
(IF ((RCW_DispF[A2,Age1]*RCW_ImmDecisionF[Area]*Corridor[A2, Area]) = RCW_DispF_1[A2,Age1]) THEN (RCW_DispF[A2,Age1]) ELSE(0)) +
(IF ((RCW_DispF[A3,Age1]*RCW_ImmDecisionF[Area]*Corridor[A3, Area]) = RCW_DispF_1[A3,Age1]) THEN (RCW_DispF[A3,Age1]) ELSE(0)) +
(IF ((RCW_DispF[A4,Age1]*RCW_ImmDecisionF[Area]*Corridor[A4, Area]) = RCW_DispF_1[A4,Age1]) THEN (RCW_DispF[A4,Age1]) ELSE(0)) +
(IF ((RCW_DispF[A5,Age1]*RCW_ImmDecisionF[Area]*Corridor[A5, Area]) = RCW_DispF_1[A5,Age1]) THEN (RCW_DispF[A5,Age1]) ELSE(0)) +
(IF ((RCW_DispF[A6,Age1]*RCW_ImmDecisionF[Area]*Corridor[A6, Area]) = RCW_DispF_1[A6,Age1]) THEN (RCW_DispF[A6,Age1]) ELSE(0)) +
(IF ((RCW_DispF[A7,Age1]*RCW_ImmDecisionF[Area]*Corridor[A7, Area]) = RCW_DispF_1[A7,Age1]) THEN (RCW_DispF[A7,Age1]) ELSE(0)) +
(IF ((RCW_DispF[A8,Age1]*RCW_ImmDecisionF[Area]*Corridor[A8, Area]) = RCW_DispF_1[A8,Age1]) THEN (RCW_DispF[A8,Age1]) ELSE(0)) +
(IF ((RCW_DispF[A9,Age1]*RCW_ImmDecisionF[Area]*Corridor[A9, Area]) = RCW_DispF_1[A9,Age1]) THEN (RCW_DispF[A9,Age1]) ELSE(0)) +
(IF ((RCW_DispF[A10,Age1]*RCW_ImmDecisionF[Area]*Corridor[A10, Area]) = RCW_DispF_1[A10,Age1]) THEN (RCW_DispF[A10,Age1]) ELSE(0)))

RCW_Imm2F2[Area,AgeGroup] = (RCW_AgeGroup[AgeGroup]=2) AND
(IF ((RCW_DispF[A11,Age1]*RCW_ImmDecisionF[Area]*Corridor[A11, Area]) = RCW_DispF_1[A11,Age1]) THEN (RCW_DispF[A11,Age1]) ELSE(0)) +
(IF ((RCW_DispF[A12,Age1]*RCW_ImmDecisionF[Area]*Corridor[A12, Area]) = RCW_DispF_1[A12,Age1]) THEN (RCW_DispF[A12,Age1]) ELSE(0)) +
(IF ((RCW_DispF[A13,Age1]*RCW_ImmDecisionF[Area]*Corridor[A13, Area]) = RCW_DispF_1[A13,Age1]) THEN (RCW_DispF[A13,Age1]) ELSE(0)) +
(IF ((RCW_DispF[A14,Age1]*RCW_ImmDecisionF[Area]*Corridor[A14, Area]) = RCW_DispF_1[A14,Age1]) THEN (RCW_DispF[A14,Age1]) ELSE(0)) +
(IF ((RCW_DispF[A15,Age1]*RCW_ImmDecisionF[Area]*Corridor[A15, Area]) = RCW_DispF_1[A15,Age1]) THEN (RCW_DispF[A15,Age1]) ELSE(0)) +
(IF ((RCW_DispF[A16,Age1]*RCW_ImmDecisionF[Area]*Corridor[A16, Area]) = RCW_DispF_1[A16,Age1]) THEN (RCW_DispF[A16,Age1]) ELSE(0)) +
(IF ((RCW_DispF[A17,Age1]*RCW_ImmDecisionF[Area]*Corridor[A17, Area]) = RCW_DispF_1[A17,Age1]) THEN (RCW_DispF[A17,Age1]) ELSE(0)) +
(IF ((RCW_DispF[A18,Age1]*RCW_ImmDecisionF[Area]*Corridor[A18, Area]) = RCW_DispF_1[A18,Age1]) THEN (RCW_DispF[A18,Age1]) ELSE(0)) +
(IF ((RCW_DispF[A19,Age1]*RCW_ImmDecisionF[Area]*Corridor[A19, Area]) = RCW_DispF_1[A19,Age1]) THEN (RCW_DispF[A19,Age1]) ELSE(0)) +

(IF ((RCW_DispF[A20,Age1]*RCW_ImmDecisionF[Area]*Corridor[A20, Area]) = RCW_DispF_1[A20,Age1]) THEN (RCW_DispF[A20,Age1]) ELSE(0)))

RCW_Imm2M[Area,AgeGroup] = RCW_Imm2M1[Area,AgeGroup]+RCW_Imm2M2[Area,AgeGroup]

RCW_Imm2M1[Area,AgeGroup] = (RCW_AgeGroup[AgeGroup]=2) AND (
(IF ((RCW_DispM[A1,Age1]*RCW_ImmDecisionM[Area]*Corridor[A1, Area]) = RCW_DispM_1[A1,Age1]) THEN (RCW_DispM[A1,Age1]) ELSE(0)) +
(IF ((RCW_DispM[A2,Age1]*RCW_ImmDecisionM[Area]*Corridor[A2, Area]) = RCW_DispM_1[A2,Age1]) THEN (RCW_DispM[A2,Age1]) ELSE(0)) +
(IF ((RCW_DispM[A3,Age1]*RCW_ImmDecisionM[Area]*Corridor[A3, Area]) = RCW_DispM_1[A3,Age1]) THEN (RCW_DispM[A3,Age1]) ELSE(0)) +
(IF ((RCW_DispM[A4,Age1]*RCW_ImmDecisionM[Area]*Corridor[A4, Area]) = RCW_DispM_1[A4,Age1]) THEN (RCW_DispM[A4,Age1]) ELSE(0)) +
(IF ((RCW_DispM[A5,Age1]*RCW_ImmDecisionM[Area]*Corridor[A5, Area]) = RCW_DispM_1[A5,Age1]) THEN (RCW_DispM[A5,Age1]) ELSE(0)) +
(IF ((RCW_DispM[A6,Age1]*RCW_ImmDecisionM[Area]*Corridor[A6, Area]) = RCW_DispM_1[A6,Age1]) THEN (RCW_DispM[A6,Age1]) ELSE(0)) +
(IF ((RCW_DispM[A7,Age1]*RCW_ImmDecisionM[Area]*Corridor[A7, Area]) = RCW_DispM_1[A7,Age1]) THEN (RCW_DispM[A7,Age1]) ELSE(0)) +
(IF ((RCW_DispM[A8,Age1]*RCW_ImmDecisionM[Area]*Corridor[A8, Area]) = RCW_DispM_1[A8,Age1]) THEN (RCW_DispM[A8,Age1]) ELSE(0)) +
(IF ((RCW_DispM[A9,Age1]*RCW_ImmDecisionM[Area]*Corridor[A9, Area]) = RCW_DispM_1[A9,Age1]) THEN (RCW_DispM[A9,Age1]) ELSE(0)) +
(IF ((RCW_DispM[A10,Age1]*RCW_ImmDecisionM[Area]*Corridor[A10, Area]) = RCW_DispM_1[A10,Age1]) THEN (RCW_DispM[A10,Age1]) ELSE(0)))

RCW_Imm2M2[Area,AgeGroup] = (RCW_AgeGroup[AgeGroup]=2) AND (
(IF ((RCW_DispM[A11,Age1]*RCW_ImmDecisionM[Area]*Corridor[A11, Area]) = RCW_DispM_1[A11,Age1]) THEN (RCW_DispM[A11,Age1]) ELSE(0)) +
(IF ((RCW_DispM[A12,Age1]*RCW_ImmDecisionM[Area]*Corridor[A12, Area]) = RCW_DispM_1[A12,Age1]) THEN (RCW_DispM[A12,Age1]) ELSE(0)) +
(IF ((RCW_DispM[A13,Age1]*RCW_ImmDecisionM[Area]*Corridor[A13, Area]) = RCW_DispM_1[A13,Age1]) THEN (RCW_DispM[A13,Age1]) ELSE(0)) +
(IF ((RCW_DispM[A14,Age1]*RCW_ImmDecisionM[Area]*Corridor[A14, Area]) = RCW_DispM_1[A14,Age1]) THEN (RCW_DispM[A14,Age1]) ELSE(0)) +
(IF ((RCW_DispM[A15,Age1]*RCW_ImmDecisionM[Area]*Corridor[A15, Area]) = RCW_DispM_1[A15,Age1]) THEN (RCW_DispM[A15,Age1]) ELSE(0)) +
(IF ((RCW_DispM[A16,Age1]*RCW_ImmDecisionM[Area]*Corridor[A16, Area]) = RCW_DispM_1[A16,Age1]) THEN (RCW_DispM[A16,Age1]) ELSE(0)) +
(IF ((RCW_DispM[A17,Age1]*RCW_ImmDecisionM[Area]*Corridor[A17, Area]) = RCW_DispM_1[A17,Age1]) THEN (RCW_DispM[A17,Age1]) ELSE(0)) +
(IF ((RCW_DispM[A18,Age1]*RCW_ImmDecisionM[Area]*Corridor[A18, Area]) = RCW_DispM_1[A18,Age1]) THEN (RCW_DispM[A18,Age1]) ELSE(0)) +
(IF ((RCW_DispM[A19,Age1]*RCW_ImmDecisionM[Area]*Corridor[A19, Area]) = RCW_DispM_1[A19,Age1]) THEN (RCW_DispM[A19,Age1]) ELSE(0)) +
(IF ((RCW_DispM[A20,Age1]*RCW_ImmDecisionM[Area]*Corridor[A20, Area]) = RCW_DispM_1[A20,Age1]) THEN (RCW_DispM[A20,Age1]) ELSE(0)))

RCW_Imm3F[Area,AgeGroup] = RCW_Imm3F1[Area,AgeGroup]+RCW_Imm3F2[Area,AgeGroup]

RCW_Imm3F1[Area,AgeGroup] = (RCW_AgeGroup[AgeGroup]=3) AND (
(IF ((RCW_DispF[A1,Age2]*RCW_ImmDecisionF[Area]*Corridor[A1, Area]) = RCW_DispF_2[A1,Age2]) THEN (RCW_DispF[A1,Age2]) ELSE(0)) +
(IF ((RCW_DispF[A2,Age2]*RCW_ImmDecisionF[Area]*Corridor[A2, Area]) = RCW_DispF_2[A2,Age2]) THEN (RCW_DispF[A2,Age2]) ELSE(0)) +

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(IF ( (RCW_DispF[A3,Age2]*RCW_ImmDecisionF[Area]*Corridor[A3, Area]) =
RCW_DispF_2[A3,Age2])       THEN (RCW_DispF[A3,Age2])      ELSE(0)) +
(IF ( (RCW_DispF[A4,Age2]*RCW_ImmDecisionF[Area]*Corridor[A4, Area]) =
RCW_DispF_2[A4,Age2])       THEN (RCW_DispF[A4,Age2])      ELSE(0)) +
(IF ( (RCW_DispF[A5,Age2]*RCW_ImmDecisionF[Area]*Corridor[A5, Area]) =
RCW_DispF_2[A5,Age2])       THEN (RCW_DispF[A5,Age2])      ELSE(0)) +
(IF ( (RCW_DispF[A6,Age2]*RCW_ImmDecisionF[Area]*Corridor[A6, Area]) =
RCW_DispF_2[A6,Age2])       THEN (RCW_DispF[A6,Age2])      ELSE(0)) +
(IF ( (RCW_DispF[A7,Age2]*RCW_ImmDecisionF[Area]*Corridor[A7, Area]) =
RCW_DispF_2[A7,Age2])       THEN (RCW_DispF[A7,Age2])      ELSE(0)) +
(IF ( (RCW_DispF[A8,Age2]*RCW_ImmDecisionF[Area]*Corridor[A8, Area]) =
RCW_DispF_2[A8,Age2])       THEN (RCW_DispF[A8,Age2])      ELSE(0)) +
(IF ( (RCW_DispF[A9,Age2]*RCW_ImmDecisionF[Area]*Corridor[A9, Area]) =
RCW_DispF_2[A9,Age2])       THEN (RCW_DispF[A9,Age2])      ELSE(0)) +
(IF ( (RCW_DispF[A10,Age2]*RCW_ImmDecisionF[Area]*Corridor[A10, Area]) =
RCW_DispF_2[A10,Age2])       THEN (RCW_DispF[A10,Age2])   ELSE(0)))

RCW_Imm3F2[Area,AgeGroup] =  (RCW_AgeGroup[AgeGroup]=3) AND   (
(IF ( (RCW_DispF[A11,Age2]*RCW_ImmDecisionF[Area]*Corridor[A11, Area])
= RCW_DispF_2[A11,Age2])       THEN (RCW_DispF[A11,Age2])  ELSE(0)) +
(IF ( (RCW_DispF[A12,Age2]*RCW_ImmDecisionF[Area]*Corridor[A12, Area])
= RCW_DispF_2[A12,Age2])       THEN (RCW_DispF[A12,Age2])  ELSE(0)) +
(IF ( (RCW_DispF[A13,Age2]*RCW_ImmDecisionF[Area]*Corridor[A13, Area])
= RCW_DispF_2[A13,Age2])       THEN (RCW_DispF[A13,Age2])  ELSE(0)) +
(IF ( (RCW_DispF[A14,Age2]*RCW_ImmDecisionF[Area]*Corridor[A14, Area])
= RCW_DispF_2[A14,Age2])       THEN (RCW_DispF[A14,Age2])  ELSE(0)) +
(IF ( (RCW_DispF[A15,Age2]*RCW_ImmDecisionF[Area]*Corridor[A15, Area])
= RCW_DispF_2[A15,Age2])       THEN (RCW_DispF[A15,Age2])  ELSE(0)) +
(IF ( (RCW_DispF[A16,Age2]*RCW_ImmDecisionF[Area]*Corridor[A16, Area])
= RCW_DispF_2[A16,Age2])       THEN (RCW_DispF[A16,Age2])  ELSE(0)) +
(IF ( (RCW_DispF[A17,Age2]*RCW_ImmDecisionF[Area]*Corridor[A17, Area])
= RCW_DispF_2[A17,Age2])       THEN (RCW_DispF[A17,Age2])  ELSE(0)) +
(IF ( (RCW_DispF[A18,Age2]*RCW_ImmDecisionF[Area]*Corridor[A18, Area])
= RCW_DispF_2[A18,Age2])       THEN (RCW_DispF[A18,Age2])  ELSE(0)) +
(IF ( (RCW_DispF[A19,Age2]*RCW_ImmDecisionF[Area]*Corridor[A19, Area])
= RCW_DispF_2[A19,Age2])       THEN (RCW_DispF[A19,Age2])  ELSE(0)) +
(IF ( (RCW_DispF[A20,Age2]*RCW_ImmDecisionF[Area]*Corridor[A20, Area])
= RCW_DispF_2[A20,Age2])       THEN (RCW_DispF[A20,Age2])  ELSE(0)))

RCW_Imm3M[Area,AgeGroup] = RCW_Imm3M1[Area,AgeGroup]+RCW_Imm3M2[Area,AgeGroup]

RCW_Imm3M1[Area,AgeGroup] =  (RCW_AgeGroup[AgeGroup]=3) AND   (
(IF ( (RCW_DispM[A1,Age2]*RCW_ImmDecisionM[Area]*Corridor[A1, Area]) =
RCW_DispM_2[A1,Age2])       THEN (RCW_DispM[A1,Age2])    ELSE(0)) +
(IF ( (RCW_DispM[A2,Age2]*RCW_ImmDecisionM[Area]*Corridor[A2, Area]) =
RCW_DispM_2[A2,Age2])       THEN (RCW_DispM[A2,Age2])    ELSE(0)) +
(IF ( (RCW_DispM[A3,Age2]*RCW_ImmDecisionM[Area]*Corridor[A3, Area]) =
RCW_DispM_2[A3,Age2])       THEN (RCW_DispM[A3,Age2])    ELSE(0)) +
(IF ( (RCW_DispM[A4,Age2]*RCW_ImmDecisionM[Area]*Corridor[A4, Area]) =
RCW_DispM_2[A4,Age2])       THEN (RCW_DispM[A4,Age2])   ELSE(0)) +
(IF ( (RCW_DispM[A5,Age2]*RCW_ImmDecisionM[Area]*Corridor[A5, Area]) =
RCW_DispM_2[A5,Age2])       THEN (RCW_DispM[A5,Age2])   ELSE(0)) +
(IF ( (RCW_DispM[A6,Age2]*RCW_ImmDecisionM[Area]*Corridor[A6, Area]) =
RCW_DispM_2[A6,Age2])       THEN (RCW_DispM[A6,Age2])   ELSE(0)) +
(IF ( (RCW_DispM[A7,Age2]*RCW_ImmDecisionM[Area]*Corridor[A7, Area]) =
RCW_DispM_2[A7,Age2])       THEN (RCW_DispM[A7,Age2])   ELSE(0)) +
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(IF ( (RCW_DispM[A8,Age2]*RCW_ImmDecisionM[Area]*Corridor[A8, Area]) =
RCW_DispM_2[A8,Age2])         THEN (RCW_DispM[A8,Age2])   ELSE(0)) +
(IF ( (RCW_DispM[A9,Age2]*RCW_ImmDecisionM[Area]*Corridor[A9, Area]) =
RCW_DispM_2[A9,Age2])         THEN (RCW_DispM[A9,Age2])   ELSE(0)) +
(IF ( (RCW_DispM[A10,Age2]*RCW_ImmDecisionM[Area]*Corridor[A10, Area]) =
RCW_DispM_2[A10,Age2])        THEN (RCW_DispM[A10,Age2])          ELSE(0)))

RCW_Imm3M2[Area,AgeGroup] = (RCW_AgeGroup[AgeGroup]=3) AND   (
(IF ( (RCW_DispM[A11,Age2]*RCW_ImmDecisionM[Area]*Corridor[A11, Area])
= RCW_DispM_2[A11,Age2])        THEN (RCW_DispM[A11,Age2])          ELSE(0)) +
(IF ( (RCW_DispM[A12,Age2]*RCW_ImmDecisionM[Area]*Corridor[A12, Area])
= RCW_DispM_2[A12,Age2])        THEN (RCW_DispM[A12,Age2])          ELSE(0)) +
(IF ( (RCW_DispM[A13,Age2]*RCW_ImmDecisionM[Area]*Corridor[A13, Area])
= RCW_DispM_2[A13,Age2])        THEN (RCW_DispM[A13,Age2])          ELSE(0)) +
(IF ( (RCW_DispM[A14,Age2]*RCW_ImmDecisionM[Area]*Corridor[A14, Area])
= RCW_DispM_2[A14,Age2])        THEN (RCW_DispM[A14,Age2])          ELSE(0)) +
(IF ( (RCW_DispM[A15,Age2]*RCW_ImmDecisionM[Area]*Corridor[A15, Area])
= RCW_DispM_2[A15,Age2])        THEN (RCW_DispM[A15,Age2])          ELSE(0)) +
(IF ( (RCW_DispM[A16,Age2]*RCW_ImmDecisionM[Area]*Corridor[A16, Area])
= RCW_DispM_2[A16,Age2])        THEN (RCW_DispM[A16,Age2])          ELSE(0)) +
(IF ( (RCW_DispM[A17,Age2]*RCW_ImmDecisionM[Area]*Corridor[A17, Area])
= RCW_DispM_2[A17,Age2])        THEN (RCW_DispM[A17,Age2])          ELSE(0)) +
(IF ( (RCW_DispM[A18,Age2]*RCW_ImmDecisionM[Area]*Corridor[A18, Area])
= RCW_DispM_2[A18,Age2])        THEN (RCW_DispM[A18,Age2])          ELSE(0)) +
(IF ( (RCW_DispM[A19,Age2]*RCW_ImmDecisionM[Area]*Corridor[A19, Area])
= RCW_DispM_2[A19,Age2])        THEN (RCW_DispM[A19,Age2])          ELSE(0)) +
(IF ( (RCW_DispM[A20,Age2]*RCW_ImmDecisionM[Area]*Corridor[A20, Area])
= RCW_DispM_2[A20,Age2])        THEN (RCW_DispM[A20,Age2])          ELSE(0)))

RCW_Imm4F[Area,AgeGroup] = RCW_Imm4F1[Area,AgeGroup]+RCW_Imm4F2[Area,AgeGroup]
RCW_Imm4F1[Area,AgeGroup] =  (RCW_AgeGroup[AgeGroup]=4) AND   (
(IF ( (RCW_DispF[A1,Age3]*RCW_ImmDecisionF[Area]*Corridor[A1, Area])
= RCW_DispF_3[A1,Age3])         THEN (RCW_DispF[A1,Age3])    ELSE(0)) +
(IF ( (RCW_DispF[A2,Age3]*RCW_ImmDecisionF[Area]*Corridor[A2, Area])
= RCW_DispF_3[A2,Age3])         THEN (RCW_DispF[A2,Age3])    ELSE(0)) +
(IF ( (RCW_DispF[A3,Age3]*RCW_ImmDecisionF[Area]*Corridor[A3, Area])
= RCW_DispF_3[A3,Age3])         THEN (RCW_DispF[A3,Age3])    ELSE(0)) +
(IF ( (RCW_DispF[A4,Age3]*RCW_ImmDecisionF[Area]*Corridor[A4, Area])
= RCW_DispF_3[A4,Age3])         THEN (RCW_DispF[A4,Age3])    ELSE(0)) +
(IF ( (RCW_DispF[A5,Age3]*RCW_ImmDecisionF[Area]*Corridor[A5, Area])
= RCW_DispF_3[A5,Age3])         THEN (RCW_DispF[A5,Age3])    ELSE(0)) +
(IF ( (RCW_DispF[A6,Age3]*RCW_ImmDecisionF[Area]*Corridor[A6, Area])
= RCW_DispF_3[A6,Age3])         THEN (RCW_DispF[A6,Age3])    ELSE(0)) +
(IF ( (RCW_DispF[A7,Age3]*RCW_ImmDecisionF[Area]*Corridor[A7, Area])
= RCW_DispF_3[A7,Age3])         THEN (RCW_DispF[A7,Age3])    ELSE(0)) +
(IF ( (RCW_DispF[A8,Age3]*RCW_ImmDecisionF[Area]*Corridor[A8, Area])
= RCW_DispF_3[A8,Age3])         THEN (RCW_DispF[A8,Age3])    ELSE(0)) +
(IF ( (RCW_DispF[A9,Age3]*RCW_ImmDecisionF[Area]*Corridor[A9, Area])
= RCW_DispF_3[A9,Age3])         THEN (RCW_DispF[A9,Age3])    ELSE(0)) +
(IF ( (RCW_DispF[A10,Age3]*RCW_ImmDecisionF[Area]*Corridor[A10, Area])
= RCW_DispF_3[A10,Age3])        THEN (RCW_DispF[A10,Age3])  ELSE(0)))

RCW_Imm4F2[Area,AgeGroup] =  (RCW_AgeGroup[AgeGroup]=4) AND   (
(IF ( (RCW_DispF[A11,Age3]*RCW_ImmDecisionF[Area]*Corridor[A11, Area])
= RCW_DispF_3[A11,Age3])        THEN (RCW_DispF[A11,Age3])  ELSE(0)) +
(IF ( (RCW_DispF[A12,Age3]*RCW_ImmDecisionF[Area]*Corridor[A12, Area])
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= RCW_DispF_3[A12,Age3])        THEN (RCW_DispF[A12,Age3])  ELSE(0)) +
(IF ( (RCW_DispF[A13,Age3]*RCW_ImmDecisionF[Area]*Corridor[A13, Area])
= RCW_DispF_3[A13,Age3])        THEN (RCW_DispF[A13,Age3])  ELSE(0)) +
(IF ( (RCW_DispF[A14,Age3]*RCW_ImmDecisionF[Area]*Corridor[A14, Area])
= RCW_DispF_3[A14,Age3])        THEN (RCW_DispF[A14,Age3])  ELSE(0)) +
(IF ( (RCW_DispF[A15,Age3]*RCW_ImmDecisionF[Area]*Corridor[A15, Area])
= RCW_DispF_3[A15,Age3])        THEN (RCW_DispF[A15,Age3])  ELSE(0)) +
(IF ( (RCW_DispF[A16,Age3]*RCW_ImmDecisionF[Area]*Corridor[A16, Area])
= RCW_DispF_3[A16,Age3])        THEN (RCW_DispF[A16,Age3])  ELSE(0)) +
(IF ( (RCW_DispF[A17,Age3]*RCW_ImmDecisionF[Area]*Corridor[A17, Area])
= RCW_DispF_3[A17,Age3])        THEN (RCW_DispF[A17,Age3])  ELSE(0)) +
(IF ( (RCW_DispF[A18,Age3]*RCW_ImmDecisionF[Area]*Corridor[A18, Area])
= RCW_DispF_3[A18,Age3])        THEN (RCW_DispF[A18,Age3])  ELSE(0)) +
(IF ( (RCW_DispF[A19,Age3]*RCW_ImmDecisionF[Area]*Corridor[A19, Area])
= RCW_DispF_3[A19,Age3])        THEN (RCW_DispF[A19,Age3])  ELSE(0)) +
(IF ( (RCW_DispF[A20,Age3]*RCW_ImmDecisionF[Area]*Corridor[A20, Area])
= RCW_DispF_3[A20,Age3])        THEN (RCW_DispF[A20,Age3])  ELSE(0)))

RCW_Imm4M[Area,AgeGroup] = RCW_Imm4M1[Area,AgeGroup]+RCW_Imm4M2[Area,AgeGroup]

RCW_Imm4M1[Area,AgeGroup] =  (RCW_AgeGroup[AgeGroup]=4) AND   (
(IF ( (RCW_DispM[A1,Age3]*RCW_ImmDecisionM[Area]*Corridor[A1, Area])
= RCW_DispM_3[A1,Age3])        THEN (RCW_DispM[A1,Age3])  ELSE(0)) +
(IF ( (RCW_DispM[A2,Age3]*RCW_ImmDecisionM[Area]*Corridor[A2, Area])
= RCW_DispM_3[A2,Age3])        THEN (RCW_DispM[A2,Age3])  ELSE(0)) +
(IF ( (RCW_DispM[A3,Age3]*RCW_ImmDecisionM[Area]*Corridor[A3, Area])
= RCW_DispM_3[A3,Age3])        THEN (RCW_DispM[A3,Age3])  ELSE(0)) +
(IF ( (RCW_DispM[A4,Age3]*RCW_ImmDecisionM[Area]*Corridor[A4, Area])
= RCW_DispM_3[A4,Age3])        THEN (RCW_DispM[A4,Age3])  ELSE(0)) +
(IF ( (RCW_DispM[A5,Age3]*RCW_ImmDecisionM[Area]*Corridor[A5, Area])
= RCW_DispM_3[A5,Age3])        THEN (RCW_DispM[A5,Age3])  ELSE(0)) +
(IF ( (RCW_DispM[A6,Age3]*RCW_ImmDecisionM[Area]*Corridor[A6, Area])
= RCW_DispM_3[A6,Age3])        THEN (RCW_DispM[A6,Age3])  ELSE(0)) +
(IF ( (RCW_DispM[A7,Age3]*RCW_ImmDecisionM[Area]*Corridor[A7, Area])
= RCW_DispM_3[A7,Age3])        THEN (RCW_DispM[A7,Age3])  ELSE(0)) +
(IF ( (RCW_DispM[A8,Age3]*RCW_ImmDecisionM[Area]*Corridor[A8, Area])
= RCW_DispM_3[A8,Age3])        THEN (RCW_DispM[A8,Age3])  ELSE(0)) +
(IF ( (RCW_DispM[A9,Age3]*RCW_ImmDecisionM[Area]*Corridor[A9, Area])
= RCW_DispM_3[A9,Age3])        THEN (RCW_DispM[A9,Age3])  ELSE(0)) +
(IF ( (RCW_DispM[A10,Age3]*RCW_ImmDecisionM[Area]*Corridor[A10, Area])
= RCW_DispM_3[A10,Age3])        THEN (RCW_DispM[A10,Age3])        ELSE(0)))

RCW_Imm4M2[Area,AgeGroup] =  (RCW_AgeGroup[AgeGroup]=4) AND   (
(IF ( (RCW_DispM[A11,Age3]*RCW_ImmDecisionM[Area]*Corridor[A11, Area])
= RCW_DispM_3[A11,Age3])        THEN (RCW_DispM[A11,Age3])        ELSE(0)) +
(IF ( (RCW_DispM[A12,Age3]*RCW_ImmDecisionM[Area]*Corridor[A12, Area])
= RCW_DispM_3[A12,Age3])        THEN (RCW_DispM[A12,Age3])        ELSE(0)) +
(IF ( (RCW_DispM[A13,Age3]*RCW_ImmDecisionM[Area]*Corridor[A13, Area])
= RCW_DispM_3[A13,Age3])        THEN (RCW_DispM[A13,Age3])        ELSE(0)) +
(IF ( (RCW_DispM[A14,Age3]*RCW_ImmDecisionM[Area]*Corridor[A14, Area])
= RCW_DispM_3[A14,Age3])        THEN (RCW_DispM[A14,Age3])        ELSE(0)) +
(IF ( (RCW_DispM[A15,Age3]*RCW_ImmDecisionM[Area]*Corridor[A15, Area])
= RCW_DispM_3[A15,Age3])        THEN (RCW_DispM[A15,Age3])        ELSE(0)) +
(IF ( (RCW_DispM[A16,Age3]*RCW_ImmDecisionM[Area]*Corridor[A16, Area])
= RCW_DispM_3[A16,Age3])        THEN (RCW_DispM[A16,Age3])        ELSE(0)) +
(IF ( (RCW_DispM[A17,Age3]*RCW_ImmDecisionM[Area]*Corridor[A17, Area])
```

= RCW_DispM_3[A17,Age3]) THEN (RCW_DispM[A17,Age3]) ELSE(0)) +
(IF ((RCW_DispM[A18,Age3]*RCW_ImmDecisionM[Area]*Corridor[A18, Area])
= RCW_DispM_3[A18,Age3]) THEN (RCW_DispM[A18,Age3]) ELSE(0)) +
(IF ((RCW_DispM[A19,Age3]*RCW_ImmDecisionM[Area]*Corridor[A19, Area])
= RCW_DispM_3[A19,Age3]) THEN (RCW_DispM[A19,Age3]) ELSE(0)) +
(IF ((RCW_DispM[A20,Age3]*RCW_ImmDecisionM[Area]*Corridor[A20, Area])
= RCW_DispM_3[A20,Age3]) THEN (RCW_DispM[A20,Age3]) ELSE(0)))

RCW_Imm5F[Area,AgeGroup] = RCW_Imm5F1[Area,AgeGroup]+RCW_Imm5F2[Area,AgeGroup]

RCW_Imm5F1[Area,AgeGroup] = (RCW_AgeGroup[AgeGroup]=5) AND (
(IF ((RCW_DispF[A1,Age4]*RCW_ImmDecisionF[Area]*Corridor[A1, Area])
= RCW_DispF_4[A1,Age4]) THEN (RCW_DispF[A1,Age4]) ELSE(0)) +
(IF ((RCW_DispF[A2,Age4]*RCW_ImmDecisionF[Area]*Corridor[A2, Area])
= RCW_DispF_4[A2,Age4]) THEN (RCW_DispF[A2,Age4]) ELSE(0)) +
(IF ((RCW_DispF[A3,Age4]*RCW_ImmDecisionF[Area]*Corridor[A3, Area])
= RCW_DispF_4[A3,Age4]) THEN (RCW_DispF[A3,Age4]) ELSE(0)) +
(IF ((RCW_DispF[A4,Age4]*RCW_ImmDecisionF[Area]*Corridor[A4, Area])
= RCW_DispF_4[A4,Age4]) THEN (RCW_DispF[A4,Age4]) ELSE(0)) +
(IF ((RCW_DispF[A5,Age4]*RCW_ImmDecisionF[Area]*Corridor[A5, Area])
= RCW_DispF_4[A5,Age4]) THEN (RCW_DispF[A5,Age4]) ELSE(0)) +
(IF ((RCW_DispF[A6,Age4]*RCW_ImmDecisionF[Area]*Corridor[A6, Area])
= RCW_DispF_4[A6,Age4]) THEN (RCW_DispF[A6,Age4]) ELSE(0)) +
(IF ((RCW_DispF[A7,Age4]*RCW_ImmDecisionF[Area]*Corridor[A7, Area])
= RCW_DispF_4[A7,Age4]) THEN (RCW_DispF[A7,Age4]) ELSE(0)) +
(IF ((RCW_DispF[A8,Age4]*RCW_ImmDecisionF[Area]*Corridor[A8, Area])
= RCW_DispF_4[A8,Age4]) THEN (RCW_DispF[A8,Age4]) ELSE(0)) +
(IF ((RCW_DispF[A9,Age4]*RCW_ImmDecisionF[Area]*Corridor[A9, Area])
= RCW_DispF_4[A9,Age4]) THEN (RCW_DispF[A9,Age4]) ELSE(0)) +
(IF ((RCW_DispF[A10,Age4]*RCW_ImmDecisionF[Area]*Corridor[A10, Area])
= RCW_DispF_4[A10,Age4]) THEN (RCW_DispF[A10,Age4]) ELSE(0)))

RCW_Imm5F2[Area,AgeGroup] = (RCW_AgeGroup[AgeGroup]=5) AND (
(IF ((RCW_DispF[A11,Age4]*RCW_ImmDecisionF[Area]*Corridor[A11, Area])
= RCW_DispF_4[A11,Age4]) THEN (RCW_DispF[A11,Age4]) ELSE(0)) +
(IF ((RCW_DispF[A12,Age4]*RCW_ImmDecisionF[Area]*Corridor[A12, Area])
= RCW_DispF_4[A12,Age4]) THEN (RCW_DispF[A12,Age4]) ELSE(0)) +
(IF ((RCW_DispF[A13,Age4]*RCW_ImmDecisionF[Area]*Corridor[A13, Area])
= RCW_DispF_4[A13,Age4]) THEN (RCW_DispF[A13,Age4]) ELSE(0)) +
(IF ((RCW_DispF[A14,Age4]*RCW_ImmDecisionF[Area]*Corridor[A14, Area])
= RCW_DispF_4[A14,Age4]) THEN (RCW_DispF[A14,Age4]) ELSE(0)) +
(IF ((RCW_DispF[A15,Age4]*RCW_ImmDecisionF[Area]*Corridor[A15, Area])
= RCW_DispF_4[A15,Age4]) THEN (RCW_DispF[A15,Age4]) ELSE(0)) +
(IF ((RCW_DispF[A16,Age4]*RCW_ImmDecisionF[Area]*Corridor[A16, Area])
= RCW_DispF_4[A16,Age4]) THEN (RCW_DispF[A16,Age4]) ELSE(0)) +
(IF ((RCW_DispF[A17,Age4]*RCW_ImmDecisionF[Area]*Corridor[A17, Area])
= RCW_DispF_4[A17,Age4]) THEN (RCW_DispF[A17,Age4]) ELSE(0)) +
(IF ((RCW_DispF[A18,Age4]*RCW_ImmDecisionF[Area]*Corridor[A18, Area])
= RCW_DispF_4[A18,Age4]) THEN (RCW_DispF[A18,Age4]) ELSE(0)) +
(IF ((RCW_DispF[A19,Age4]*RCW_ImmDecisionF[Area]*Corridor[A19, Area])
= RCW_DispF_4[A19,Age4]) THEN (RCW_DispF[A19,Age4]) ELSE(0)) +
(IF ((RCW_DispF[A20,Age4]*RCW_ImmDecisionF[Area]*Corridor[A20, Area])
= RCW_DispF_4[A20,Age4]) THEN (RCW_DispF[A20,Age4]) ELSE(0)))

RCW_Imm5M[Area,AgeGroup] = RCW_Imm5M1[Area,AgeGroup]+RCW_Imm5M2[Area,AgeGroup]

```
RCW_Imm5M1[Area,AgeGroup] = (RCW_AgeGroup[AgeGroup]=5) AND (
(IF ( (RCW_DispM[A1,Age4]*RCW_ImmDecisionM[Area]*Corridor[A1, Area])
= RCW_DispM_4[A1,Age4])        THEN (RCW_DispM[A1,Age4])  ELSE(0)) +
(IF ( (RCW_DispM[A2,Age4]*RCW_ImmDecisionM[Area]*Corridor[A2, Area])
= RCW_DispM_4[A2,Age4])        THEN (RCW_DispM[A2,Age4])  ELSE(0)) +
(IF ( (RCW_DispM[A3,Age4]*RCW_ImmDecisionM[Area]*Corridor[A3, Area])
= RCW_DispM_4[A3,Age4])        THEN (RCW_DispM[A3,Age4])  ELSE(0)) +
(IF ( (RCW_DispM[A4,Age4]*RCW_ImmDecisionM[Area]*Corridor[A4, Area])
= RCW_DispM_4[A4,Age4])        THEN (RCW_DispM[A4,Age4])  ELSE(0)) +
(IF ( (RCW_DispM[A5,Age4]*RCW_ImmDecisionM[Area]*Corridor[A5, Area])
= RCW_DispM_4[A5,Age4])        THEN (RCW_DispM[A5,Age4])  ELSE(0)) +
(IF ( (RCW_DispM[A6,Age4]*RCW_ImmDecisionM[Area]*Corridor[A6, Area])
= RCW_DispM_4[A6,Age4])        THEN (RCW_DispM[A6,Age4])  ELSE(0)) +
(IF ( (RCW_DispM[A7,Age4]*RCW_ImmDecisionM[Area]*Corridor[A7, Area])
= RCW_DispM_4[A7,Age4])        THEN (RCW_DispM[A7,Age4])  ELSE(0)) +
(IF ( (RCW_DispM[A8,Age4]*RCW_ImmDecisionM[Area]*Corridor[A8, Area])
= RCW_DispM_4[A8,Age4])        THEN (RCW_DispM[A8,Age4])  ELSE(0)) +
(IF ( (RCW_DispM[A9,Age4]*RCW_ImmDecisionM[Area]*Corridor[A9, Area])
= RCW_DispM_4[A9,Age4])        THEN (RCW_DispM[A9,Age4])  ELSE(0)) +
(IF ( (RCW_DispM[A10,Age4]*RCW_ImmDecisionM[Area]*Corridor[A10, Area])
= RCW_DispM_4[A10,Age4])       THEN (RCW_DispM[A10,Age4])       ELSE(0)))

RCW_Imm5M2[Area,AgeGroup] = (RCW_AgeGroup[AgeGroup]=5) AND (
(IF ( (RCW_DispM[A11,Age4]*RCW_ImmDecisionM[Area]*Corridor[A11, Area])
= RCW_DispM_4[A11,Age4])       THEN (RCW_DispM[A11,Age4])       ELSE(0)) +
(IF ( (RCW_DispM[A12,Age4]*RCW_ImmDecisionM[Area]*Corridor[A12, Area])
= RCW_DispM_4[A12,Age4])       THEN (RCW_DispM[A12,Age4])       ELSE(0)) +
(IF ( (RCW_DispM[A13,Age4]*RCW_ImmDecisionM[Area]*Corridor[A13, Area])
= RCW_DispM_4[A13,Age4])       THEN (RCW_DispM[A13,Age4])       ELSE(0)) +
(IF ( (RCW_DispM[A14,Age4]*RCW_ImmDecisionM[Area]*Corridor[A14, Area])
= RCW_DispM_4[A14,Age4])       THEN (RCW_DispM[A14,Age4])       ELSE(0)) +
(IF ( (RCW_DispM[A15,Age4]*RCW_ImmDecisionM[Area]*Corridor[A15, Area])
= RCW_DispM_4[A15,Age4])       THEN (RCW_DispM[A15,Age4])       ELSE(0)) +
(IF ( (RCW_DispM[A16,Age4]*RCW_ImmDecisionM[Area]*Corridor[A16, Area])
= RCW_DispM_4[A16,Age4])       THEN (RCW_DispM[A16,Age4])       ELSE(0)) +
(IF ( (RCW_DispM[A17,Age4]*RCW_ImmDecisionM[Area]*Corridor[A17, Area])
= RCW_DispM_4[A17,Age4])       THEN (RCW_DispM[A17,Age4])       ELSE(0)) +
(IF ( (RCW_DispM[A18,Age4]*RCW_ImmDecisionM[Area]*Corridor[A18, Area])
= RCW_DispM_4[A18,Age4])       THEN (RCW_DispM[A18,Age4])       ELSE(0)) +
(IF ( (RCW_DispM[A19,Age4]*RCW_ImmDecisionM[Area]*Corridor[A19, Area])
= RCW_DispM_4[A19,Age4])       THEN (RCW_DispM[A19,Age4])       ELSE(0)) +
(IF ( (RCW_DispM[A20,Age4]*RCW_ImmDecisionM[Area]*Corridor[A20, Area])
= RCW_DispM_4[A20,Age4])       THEN (RCW_DispM[A20,Age4])       ELSE(0)))

RCW_ImmDecisionF[Area] =
IF(RCW_BreedingM[Area]>=1)THEN(RCW_ImmPotential[Area])ELSE(RCW_ImmPotential[Area]*
RCW_BreedMImmEffectF)

RCW_ImmDecisionM[Area] =
IF(RCW_BreedingM[Area]>=1)THEN(RCW_ImmPotential[Area]*RCW_BreedMImmEffectM)ELSE
(RCW_ImmPotential[Area])

RCW_ImmMortF[Area] = (RCW_FledgDispF[Area]-RCW_ImmF[Area,Age1])+
(RCW_DispF[Area,Age1]-RCW_ImmF[Area,Age2])+
(RCW_DispF[Area,Age2]-RCW_ImmF[Area,Age3])+
(RCW_DispF[Area,Age3]-RCW_ImmF[Area,Age4])+ (RCW_DispF[Area,Age4]-RCW_ImmF[Area,Age5plus])
```

RCW_ImmMortM[Area] = (RCW_FledgDispM[Area]-RCW_ImmM[Area,Age1])+
(RCW_DispM[Area,Age1]-RCW_ImmM[Area,Age2])+
(RCW_DispM[Area,Age2]-RCW_ImmM[Area,Age3])+
(RCW_DispM[Area,Age3]-RCW_ImmM[Area,Age4])+
(RCW_DispM[Area,Age4]-RCW_ImmM[Area,Age5plus])

RCW_ImmPotential[Area] =
(CavIndexImmWt*CavIndex[Area]+ForIndexImmWt*ForagingIndex[Area])/ImmPotTotWt

RCW_ImmTotF[Area,AgeGroup] =
AF_1&2&3&4[Area,AgeGroup]+AF_5&6&7&8[Area,AgeGroup]+AF_9&10&11&12[Area,AgeGroup]+
AF_13&14&15&16[Area,AgeGroup]+AF_17&18&19&20[Area,AgeGroup]

RCW_ImmTotM[Area,AgeGroup] =
AM_1&2&3&4[Area,AgeGroup]+AM_5&6&7&8[Area,AgeGroup]+AM_9&10&11&12[Area,AgeGroup]+
AM_13&14&15&16[Area,AgeGroup]+AM_17&18&19&20[Area,AgeGroup]

RCW_Imm_F[Area,AgeGroup] =
RCW_Imm2F[Area,AgeGroup]+RCW_Imm3F[Area,AgeGroup]+RCW_Imm4F[Area,AgeGroup]+
RCW_Imm5F[Area,AgeGroup]+RCW_Imm1F[Area,AgeGroup]

RCW_Imm_M[Area,AgeGroup] =
RCW_Imm2M[Area,AgeGroup]+RCW_Imm3M[Area,AgeGroup]+RCW_Imm4M[Area,AgeGroup]+
RCW_Imm5M[Area,AgeGroup]+RCW_Imm1M[Area,AgeGroup]

RCW_MArea[A1] = 0	RCW_MArea[A6] = 0	RCW_MArea[A11] = 0	RCW_MArea[A16] = 0
RCW_MArea[A2] = 0	RCW_MArea[A7] = 0	RCW_MArea[A12] = 0	RCW_MArea[A17] = 0
RCW_MArea[A3] = 1	RCW_MArea[A8] = 0	RCW_MArea[A13] = 0	RCW_MArea[A18] = 0
RCW_MArea[A4] = 0	RCW_MArea[A9] = 0	RCW_MArea[A14] = 1	RCW_MArea[A19] = 0
RCW_MArea[A5] = 0	RCW_MArea[A10] = 1	RCW_MArea[A15] = 0	RCW_MArea[A20] = 0

RCW_MTrans[Area,AgeGroup] =
RCW_MArea[Area]*(RCW_TransM1[AgeGroup]*RCW_Trans1MYN+RCW_TransM2[AgeGroup]*
RCW_Trans2MYN)

RCW_RangeF = ARRAYSUM(RCW_AreaF[*])

RCW_RangeM = ARRAYSUM(RCW_AreaM[*])

RCW_RangePop = RCW_RangeF+RCW_RangeM

RCW_RangeTotF = ARRAYSUM(RCW_AreaTotF[*])

RCW_RangeTotM = ARRAYSUM(RCW_AreaTotM[*])

RCW_RangeTotPop = RCW_RangeTotF+RCW_RangeTotM

RCW_TotAreaPop[Area] = RCW_AreaTotF[Area]+RCW_AreaTotM[Area]

RCW_Trans1FYN = 0

RCW_Trans1MYN = 0

RCW_Trans2FYN = 1

RCW_Trans2MYN = 1

RCW_TransF1[Age1] = 1
RCW_TransF1[Age2] = 0
RCW_TransF1[Age3] = 0
RCW_TransF1[Age4] = 0
RCW_TransF1[Age5plus] = 0
RCW_TransF2[Age1] = 0
RCW_TransF2[Age2] = 1
RCW_TransF2[Age3] = 0
RCW_TransF2[Age4] = 0
RCW_TransF2[Age5plus] = 0

RCW_TransFreq[Area] = 15

RCW_Translocation[Area] =
PULSE(1,RCW_FirstTrans[Area],RCW_TransFreq[Area])*RCW_TransYesNo

RCW_TransM1[Age1] = 1
RCW_TransM1[Age2] = 0
RCW_TransM1[Age3] = 0
RCW_TransM1[Age4] = 0
RCW_TransM1[Age5plus] = 0
RCW_TransM2[Age1] = 0
RCW_TransM2[Age2] = 1
RCW_TransM2[Age3] = 0
RCW_TransM2[Age4] = 0
RCW_TransM2[Age5plus] = 0

RCW_TransYesNo = 0

RCW_BirthRateF[Area] = GRAPH(RCW_BreedingPair[Area])

(0.00, 0.00), (1.00, 0.33), (2.00, 0.75), (3.00, 1.04), (4.00, 1.26), (5.00, 1.45), (6.00, 1.59), (7.00, 1.70), (8.00, 1.81), (9.00, 1.90), (10.0, 1.98)

RCW_BirthRateM[Area] = GRAPH(RCW_BreedingPair[Area])

(0.00, 0.00), (1.00, 0.35), (2.00, 0.69), (3.00, 0.95), (4.00, 1.19), (5.00, 1.38), (6.00, 1.54), (7.00, 1.68), (8.00, 1.80), (9.00, 1.90), (10.0, 2.00)

RCW_FledgDispDecisionF[Area] = GRAPH(RCW_DispPotential[Area])

(0.00, 0.005), (0.1, 0.035), (0.2, 0.1), (0.3, 0.215), (0.4, 0.375), (0.5, 0.575), (0.6, 0.83), (0.7, 0.95), (0.8, 1.00), (0.9, 1.00), (1, 1.00)

RCW_FledgDispDecisionM[Area] = GRAPH(RCW_DispPotential[Area])

(0.00, 0.00), (0.1, 0.095), (0.2, 0.19), (0.3, 0.275), (0.4, 0.365), (0.5, 0.485), (0.6, 0.585), (0.7, 0.685), (0.8, 0.77), (0.9, 0.885), (1, 1.00)

RCW_FledgMortRate[Area] = GRAPH(ForagingIndex[Area])

(0.00, 1.00), (0.1, 0.755), (0.2, 0.6), (0.3, 0.485), (0.4, 0.425), (0.5, 0.385), (0.6, 0.35), (0.7, 0.32), (0.8, 0.31), (0.9, 0.295), (1, 0.295)

RCW_HelperEffect[Area] = GRAPH(RCW_AreaHelpers[Area])

(0.00, 1.00), (0.5, 1.00), (1.00, 0.875), (1.50, 0.875), (2.00, 0.8), (2.50, 0.8), (3.00, 0.75), (3.50, 0.75), (4.00, 0.75), (4.50, 0.75), (5.00, 0.75)

RCW_MortRate[Area] = GRAPH(ForagingIndex[Area])

(0.00, 1.00), (0.1, 0.8), (0.2, 0.66), (0.3, 0.555), (0.4, 0.465), (0.5, 0.395), (0.6, 0.345), (0.7, 0.295), (0.8, 0.27), (0.9, 0.245), (1, 0.245)

Silviculture

HWCutYesNo[Area] = 0

HWFirstCut[Area] = 8

HWInterval[Area] = 10

HWPolePercentCut[Area] = 1

HWSilvi[Area] = PULSE(1,HWFirstCut[Area],HWInterval[Area])*HWCutYesNo[Area]

LLFCutYesNo[Area] = 0

LLFFirstCut[Area] = 50

LLFInterval[Area] = 25

LLFLPolePercentCut[Area] = 0.2

LLFMaturePercentCut[Area] = 0

LLFOGPercentCut[Area] = 0

LLFSilvi[Area] = PULSE(1,LLFFirstCut[Area],LLFInterval[Area])*LLFCutYesNo[Area]

LLFSPolePercentCut[Area] = 0.2

SLCutYesNo[Area] = 0

SLFirstCut[Area] = 100

SLInterval[Area] = 0

SLLPolePercentCut[Area] = 1

SLMaturePercentCut[Area] = 0.75

SLSilvi[Area] = PULSE(1,SLFirstCut[Area],SLInterval[Area])*SLCutYesNo[Area]

SLSPolePercentCut[Area] = 1

Slash Pine

SLLargePole[**AREA**](t) = SLLargePole[**AREA**](t - dt) + (SLSPoleToLPole[**AREA**] - SLLPoleToMat[**AREA**] - SLLPoleMort[**AREA**]) * dt

TRANSIT TIME = 30
INFLOW LIMIT = INF
CAPACITY = INF

INIT SLLargePole[A1] = 12818
INIT SLLargePole[A2] = 4
INIT SLLargePole[A3] = 34
INIT SLLargePole[A4] = 5916
INIT SLLargePole[A5] = 578
INIT SLLargePole[A6] = 9452
INIT SLLargePole[A7] = 9588
INIT SLLargePole[A8] = 0
INIT SLLargePole[A9] = 0

INIT SLLargePole[A10] = 5882
INIT SLLargePole[A11] = 17476
INIT SLLargePole[A12] = 4862
INIT SLLargePole[A13] = 8194
INIT SLLargePole[A14] = 10540
INIT SLLargePole[A15] = 11560
INIT SLLargePole[A16] = 21182
INIT SLLargePole[A17] = 2244
INIT SLLargePole[A18] = 5168
INIT SLLargePole[A19] = 15300
INIT SLLargePole[A20] = 7140

INFLOWS:

SLSPoleToLPole[Area] = CONVEYOR OUTFLOW

OUTFLOWS:

SLLPoleToMat[Area] = CONVEYOR OUTFLOW
SLLPoleMort[Area] = LEAKAGE OUTFLOW

LEAKAGE FRACTION =
SLLPoleMortRate[Area]+SLLPoleFireLoss[Area]*FireMortMag+SLLPoleConRate[Area]+
SLLPolePercentCut[Area]*SLSilvi[Area]

NO-LEAK ZONE = 0

SLMature**[AREA]**(t) = SLMature**[AREA]**(t - dt) + (SLLPoleToMat**[AREA]** - SLMatMort**[AREA]**) * dt

INIT SLMature[A1] = 2600
INIT SLMature[A2] = 100
INIT SLMature[A3] = 50
INIT SLMature[A4] = 4700
INIT SLMature[A5] = 300
INIT SLMature[A6] = 400
INIT SLMature[A7] = 5500
INIT SLMature[A8] = 0
INIT SLMature[A9] = 0
INIT SLMature[A10] = 1400
INIT SLMature[A11] = 3600
INIT SLMature[A12] = 3100
INIT SLMature[A13] = 3600
INIT SLMature[A14] = 7500
INIT SLMature[A15] = 7100
INIT SLMature[A16] = 6000
INIT SLMature[A17] = 1800
INIT SLMature[A18] = 7400
INIT SLMature[A19] = 9400
INIT SLMature[A20] = 7840

INFLOWS:

SLLPoleToMat[Area] = CONVEYOR OUTFLOW

OUTFLOWS:

SLMatMort[Area] =
SLMature[Area]*(SLMatMortRate[Area]+SLMatConRate[Area]+SLMatureFireLoss[Area]*
FireMortMag+SLMaturePercentCut[Area]*SLSilvi[Area])

SLSapling**[AREA]**(t) = SLSapling**[AREA]**(t - dt) + (SLSeedToSap**[AREA]** - SLSapToSPole**[AREA]** -
SLSapMort**[AREA]**) * dt

TRANSIT TIME = 15
INFLOW LIMIT = INF
CAPACITY = INF

INIT SLSapling[A1] = 31000
INIT SLSapling[A2] = 500
INIT SLSapling[A3] = 250
INIT SLSapling[A4] = 30000
INIT SLSapling[A5] = 2000
INIT SLSapling[A6] = 17000
INIT SLSapling[A7] = 43000
INIT SLSapling[A8] = 0
INIT SLSapling[A9] = 0
INIT SLSapling[A10] = 22000
INIT SLSapling[A11] = 48000
INIT SLSapling[A12] = 15000
INIT SLSapling[A13] = 24000
INIT SLSapling[A14] = 39000
INIT SLSapling[A15] = 35000
INIT SLSapling[A16] = 44000
INIT SLSapling[A17] = 8000
INIT SLSapling[A18] = 26000
INIT SLSapling[A19] = 48000
INIT SLSapling[A20] = 28000

INFLOWS:

SLSeedToSap[Area] = CONVEYOR OUTFLOW

OUTFLOWS:

SLSapToSPole[Area] = CONVEYOR OUTFLOW
SLSapMort[Area] = LEAKAGE OUTFLOW

LEAKAGE FRACTION = SLSapMortRate[Area]+SLSapFireLoss[Area]+SLSapConRate[Area]

NO-LEAK ZONE = 0

SLSeedling[**AREA**](t) = SLSeedling[**AREA**](t - dt) + (SLRegeneration[**AREA**] - SLSeedToSap[**AREA**] - SLSeedMort[**AREA**]) * dt

TRANSIT TIME = 3
INFLOW LIMIT = INF
CAPACITY = INF

INIT SLSeedling[A1] = 77500
INIT SLSeedling[A2] = 1000
INIT SLSeedling[A3] = 500
INIT SLSeedling[A4] = 75000
INIT SLSeedling[A5] = 5000
INIT SLSeedling[A6] = 42500
INIT SLSeedling[A7] = 107500
INIT SLSeedling[A8] = 0
INIT SLSeedling[A9] = 0
INIT SLSeedling[A10] = 55000
INIT SLSeedling[A11] = 120000
INIT SLSeedling[A12] = 37500
INIT SLSeedling[A13] = 60000
INIT SLSeedling[A14] = 97500
INIT SLSeedling[A15] = 87500
INIT SLSeedling[A16] = 110000
INIT SLSeedling[A17] = 20000
INIT SLSeedling[A18] = 65000
INIT SLSeedling[A19] = 120000
INIT SLSeedling[A20] = 70000

INFLOWS:

SLRegeneration[Area] =
SLSeeding*SLSeedTrees[Area]*SLShadeEffect[Area]*SLHWchoke[Area]*SLFireEffect[Area]

OUTFLOWS:

SLSeedToSap[Area] = CONVEYOR OUTFLOW
SLSeedMort[Area] = LEAKAGE OUTFLOW

LEAKAGE FRACTION =
SLSeedMortRate[Area]+SLSeedFireLoss[Area]+SLSeedConRate[Area]

NO-LEAK ZONE = 0

SLSmallPole[**AREA**](t) = SLSmallPole[**AREA**](t - dt) + (SLSapToSPole[**AREA**] - SLSPoleToLPole[**AREA**] - SLSPoleMort[**AREA**]) * dt

TRANSIT TIME = 15
INFLOW LIMIT = INF
CAPACITY = INF

INIT SLSmallPole[A1] = 24882
INIT SLSmallPole[A2] = 7
INIT SLSmallPole[A3] = 66
INIT SLSmalPole[A4] = 11484
INIT SLSmallPole[A5] = 1122
INIT SLSmallPole[A6] = 18348
INIT SLSmallPole[A7] = 18612
INIT SLSmallPole[A8] = 0
INIT SLSmallPole[A9] = 0
INIT SLSmallPole[A10] = 11418
INIT SLSmallPole[A11] = 33924
INIT SLSmallPole[A12] = 9438
INIT SLSmallPole[A13] = 15906
INIT SLSmallPole[A14] = 20460
INIT SLSmallPole[A15] = 22440
INIT SLSmallPole[A16] = 41118
INIT SLSmallPole[A17] = 4356
INIT SLSmallPole[A18] = 10032
INIT SLSmallPole[A19] = 29700
INIT SLSmallPole[A20] = 13860

INFLOWS:

SLSapToSPole[Area] = CONVEYOR OUTFLOW

OUTFLOWS:

SLSPoleToLPole[Area] = CONVEYOR OUTFLOW
SLSPoleMort[Area] = LEAKAGE OUTFLOW

LEAKAGE FRACTION =
SLSPoleMortRate[Area]+SLSPoleFireLoss[Area]*FireMortMag+SLSPoleConRate[Area]+
SLSPolePercentCut[Area]*SLSilvi[Area]

NO-LEAK ZONE = 0

SLLPoleCon[Area] = LLFConversion[Area]*SLLPoleDen[Area]

SLLPoleConRate[Area] =
IF(SLAreaAcreage[Area]=0)THEN(1)ELSE(IF(SLLargePole[Area]=0)THEN(0)ELSE(SLLPoleCon[Area]
/SLLargePole[Area]))

SLLPoleDen[Area] =
IF(SLAreaAcreage[Area]=0)THEN(0)ELSE(SLLargePole[Area]/SLAreaAcreage[Area])

SLMatCon[Area] = LLFConversion[Area]*SLMatureDen[Area]

SLMatConRate[Area] =
IF(SLAreaAcreage[Area]=0)THEN(1)ELSE(IF(SLMature[Area]=0)THEN(0)ELSE(SLMatCon[Area]/
SLMature[Area]))

SLMatureDen[Area] =
IF(SLAreaAcreage[Area]=0)THEN(0)ELSE(SLMature[Area]/SLAreaAcreage[Area])

SLSapCon[Area] = LLFConversion[Area]*SLSaplingDen[Area]

SLSapConRate[Area] =
IF(SLAreaAcreage[Area]=0)THEN(1)ELSE(IF(SLSapling[Area]=0)THEN(0)ELSE(SLSapCon[Area]/
SLSapling[Area]))

SLSaplingDen[Area] =
IF(SLAreaAcreage[Area]=0)THEN(0)ELSE(SLSapling[Area]/SLAreaAcreage[Area])

SLSeedCon[Area] = LLFConversion[Area]*SLSeedlingDen[Area]

SLSeedConRate[Area] =
IF(SLAreaAcreage[Area]=0)THEN(1)ELSE(IF(SLSeedling[Area]=0)THEN(0)ELSE(SLSeedCon[Area]/
SLSeedling[Area]))

SLSeeding = 25

SLSeedlingDen[Area] =
IF(SLAreaAcreage[Area]=0)THEN(0)ELSE(SLSeedling[Area]/SLAreaAcreage[Area])

SLSeedTrees[Area] = SLLargePole[Area]*0.25+SLMature[Area]

SLSPoleCon[Area] = LLFConversion[Area]*SLSPoleDen[Area]

SLSPoleConRate[Area] =
IF(SLAreaAcreage[Area]=0)THEN(1)ELSE(IF(SLSmallPole[Area]=0)THEN(0)ELSE(SLSPoleCon[Area]
/SLSmallPole[Area]))

SLSPoleDen[Area] =
IF(SLAreaAcreage[Area]=0)THEN(0)ELSE(SLSmallPole[Area]/SLAreaAcreage[Area])

SlTreeDen[Area] = IF(SLAreaAcreage[Area]=0)THEN(0)ELSE(SLTrees[Area]/SLAreaAcreage[Area])

SLTrees[Area] = SLSmallPole[Area]*0.75+SLLargePole[Area]+SLMature[Area]

SLFireEffect[Area] = GRAPH(FireEffect[Area])

(0.00, 0.305), (0.1, 0.375), (0.2, 0.435), (0.3, 0.505), (0.4, 0.575), (0.5, 0.655), (0.6, 0.725), (0.7, 0.785),
(0.8, 0.855), (0.9, 0.925), (1, 1.00)

SLHWchoke[Area] = GRAPH(HWFactor[Area])

(0.00, 1.00), (50.0, 0.955), (100, 0.89), (150, 0.795), (200, 0.695), (250, 0.55), (300, 0.43), (350, 0.29),
(400, 0.165), (450, 0.06), (500, 0.00)

SLLPoleFireLoss[Area] = GRAPH(Fire[Area])

(0.00, 0.00), (0.1, 0.00), (0.2, 0.00), (0.3, 0.00), (0.4, 0.00), (0.5, 0.00), (0.6, 0.00), (0.7, 0.01), (0.8, 0.05),
(0.9, 0.1), (1, 0.19)

SLLPoleMortRate[Area] = GRAPH(SLLPoleDen[Area])

(0.00, 0.0375), (17.5, 0.0375), (35.0, 0.0375), (52.5, 0.0375), (70.0, 0.0375), (87.5, 0.0375), (105, 0.0375),
(123, 0.0375), (140, 0.04), (158, 0.0625), (175, 0.124)

SLMatMortRate[Area] = GRAPH(SLMatureDen[Area])

(0.00, 0.025), (7.50, 0.025), (15.0, 0.025), (22.5, 0.025), (30.0, 0.025), (37.5, 0.025), (45.0, 0.025),
(52.5, 0.025), (60.0, 0.035), (67.5, 0.0525), (75.0, 0.116)

SLMatureFireLoss[Area] = GRAPH(Fire[Area])

(0.00, 0.00), (0.1, 0.00), (0.2, 0.00), (0.3, 0.00), (0.4, 0.00), (0.5, 0.00), (0.6, 0.00), (0.7, 0.01), (0.8, 0.05),
(0.9, 0.1), (1, 0.21)

SLSapFireLoss[Area] = GRAPH(Fire[Area])

(0.00, 0.00), (0.1, 0.03), (0.2, 0.06), (0.3, 0.09), (0.4, 0.13), (0.5, 0.18), (0.6, 0.26), (0.7, 0.37), (0.8, 0.51),
(0.9, 0.7), (1, 1.00)

SLSapMortRate[Area] = GRAPH(SLSaplingDen[Area])

(0.00, 0.075), (50.0, 0.075), (100, 0.075), (150, 0.075), (200, 0.075), (250, 0.075), (300, 0.075), (350, 0.08),
(400, 0.085), (450, 0.1), (500, 0.133)

SLSeedFireLoss[Area] = GRAPH(Fire[Area])

(0.00, 0.00), (0.1, 0.51), (0.2, 0.67), (0.3, 0.77), (0.4, 0.83), (0.5, 0.89), (0.6, 0.92), (0.7, 0.95), (0.8, 0.97),
(0.9, 0.99), (1, 1.00)

SLSeedMortRate[Area] = GRAPH(SLSeedlingDen[Area])

(0.00, 0.177), (100, 0.177), (200, 0.177), (300, 0.177), (400, 0.188), (500, 0.198), (600, 0.21), (700, 0.23), (800, 0.255), (900, 0.288), (1000, 0.343)

SLShadeEffect[Area] = GRAPH(SlTreeDen[Area])

(0.00, 1.00), (100, 0.72), (200, 0.54), (300, 0.41), (400, 0.3), (500, 0.21), (600, 0.15), (700, 0.09), (800, 0.05), (900, 0.02), (1000, 0.005)

SLSPoleFireLoss[Area] = GRAPH(Fire[Area])

(0.00, 0.00), (0.1, 0.00), (0.2, 0.00), (0.3, 0.00), (0.4, 0.00), (0.5, 0.00), (0.6, 0.02), (0.7, 0.04), (0.8, 0.07), (0.9, 0.12), (1, 0.29)

SLSPoleMortRate[Area] = GRAPH(SLSPoleDen[Area])

(0.00, 0.05), (40.0, 0.05), (80.0, 0.05), (120, 0.05), (160, 0.05), (200, 0.05), (240, 0.05), (280, 0.05), (320, 0.0575), (360, 0.0725), (400, 0.149)

Southern Flying Squirrel

SFSAdult[**AREA**](t) = SFSAdult[**AREA**](t - dt) + (SFSGrowth[**AREA**] - SFSAdultCapture[**AREA**] - SFSAdultMort[**AREA**]) * dt

INIT SFSAdult[A1] = 10
INIT SFSAdult[A2] = 8
INIT SFSAdult[A3] = 0
INIT SFSAdult[A4] = 1
INIT SFSAdult[A5] = 9
INIT SFSAdult[A6] = 0
INIT SFSAdult[A7] = 10
INIT SFSAdult[A8] = 1
INIT SFSAdult[A9] = 4
INIT SFSAdult[A10] = 9
INIT SFSAdult[A11] = 8
INIT SFSAdult[A12] = 0
INIT SFSAdult[A13] = 5
INIT SFSAdult[A14] = 4
INIT SFSAdult[A15] = 2
INIT SFSAdult[A16] = 6
INIT SFSAdult[A17] = 2
INIT SFSAdult[A18] = 1
INIT SFSAdult[A19] = 4
INIT SFSAdult[A20] = 0

INFLOWS:

SFSGrowth[Area] = SFSJuvenile[Area]

OUTFLOWS:

SFSAdultCapture[Area] = SFSAdult[Area]*SFSRemoval[Area]

SFSAdultMort[Area] = SFSAdult[Area]*SFSMortRate[Area]*(1-SFSFoodFactor[Area])

SFSJuvenile[**AREA**](t) = SFSJuvenile[**AREA**](t - dt) + (SFSBirths[**AREA**] - SFSJuvCapture[**AREA**] - SFS_JuvMort[**AREA**] - SFSGrowth[**AREA**]) * dt

INIT SFSJuvenile[A1] = 5
INIT SFSJuvenile[A2] = 4
INIT SFSJuvenile[A3] = 0
INIT SFSJuvenile[A4] = 1
INIT SFSJuvenile[A5] = 4
INIT SFSJuvenile[A6] = 0
INIT SFSJuvenile[A7] = 5
INIT SFSJuvenile[A8] = 1
INIT SFSJuvenile[A9] = 2
INIT SFSJuvenile[A10] = 5
INIT SFSJuvenile[A11] = 4
INIT SFSJuvenile[A12] = 0
INIT SFSJuvenile[A13] = 3
INIT SFSJuvenile[A14] = 2
INIT SFSJuvenile[A15] = 1
INIT SFSJuvenile[A16] = 3
INIT SFSJuvenile[A17] = 1
INIT SFSJuvenile[A18] = 0
INIT SFSJuvenile[A19] = 2
INIT SFSJuvenile[A20] = 0

INFLOWS:

SFSBirths[Area] = SFSAdult[Area]*SFSBirthRate*SFSFoodFactor[Area]

OUTFLOWS:

SFSJuvCapture[Area] = SFSJuvenile[Area]*SFSRemoval[Area]

SFS_JuvMort[Area] = SFSJuvenile[Area]*SFSJuvMortRate[Area]*(1-SFSFoodFactor[Area])

SFSGrowth[Area] = SFSJuvenile[Area]

SFSAdultTot = ARRAYSUM(SFSAdult[*])

SFSBirthRate = 1.5

SFSFoodRatio[Area] =
IF(SFSFoodReqmts[Area]=0)THEN(0)ELSE(HWPole[Area]/SFSFoodReqmts[Area])

SFSFoodReqmts[Area] = SFSAdult[Area]+0.5*SFSJuvenile[Area]

SFSJuvTot = ARRAYSUM(SFSJuvenile[*])

SFSRemoval[Area] =
PULSE(SFSCaptureRate,SFSFirstCap[Area],SFSCapFreq[Area])*SFSCaptureYesNo

SFSFoodFactor[Area] = GRAPH(SFSFoodRatio[Area])

(0.00, 0.00), (60.0, 0.1), (120, 0.2), (180, 0.3), (240, 0.4), (300, 0.5), (360, 0.6), (420, 0.7), (480, 0.8), (540, 0.9), (600, 1.00)

SFSJuvMortRate[Area] = GRAPH(SFSJuvenile[Area])

(0.00, 0.5), (3.00, 0.5), (6.00, 0.5), (9.00, 0.5), (12.0, 0.5), (15.0, 0.51), (18.0, 0.54), (21.0, 0.6), (24.0, 0.675), (27.0, 0.78), (30.0, 1.00)

SFSMortRate[Area] = GRAPH(SFSAdult[Area])

(0.00, 0.3), (3.00, 0.3), (6.00, 0.3), (9.00, 0.3), (12.0, 0.315), (15.0, 0.34), (18.0, 0.38), (21.0, 0.46), (24.0, 0.565), (27.0, 0.73), (30.0, 1.00)

Not in a Sector

CavArtAmt = 2

CavArtFirst[A1] = 0	CavArtFirst[A6] = 1	CavArtFirst[A11] = 1	CavArtFirst[A16] = 1
CavArtFirst[A2] = 1	CavArtFirst[A7] = 2	CavArtFirst[A12] = 2	CavArtFirst[A17] = 2
CavArtFirst[A3] = 2	CavArtFirst[A8] = 3	CavArtFirst[A13] = 3	CavArtFirst[A18] = 3
CavArtFirst[A4] = 3	CavArtFirst[A9] = 4	CavArtFirst[A14] = 4	CavArtFirst[A19] = 4
CavArtFirst[A5] = 0	CavArtFirst[A10] = 0	CavArtFirst[A15] = 0	CavArtFirst[A20] = 0

CavArtFreq = 10

CavArtInstall[Area] = Pulse(CavArtAmt,CavArtFirst[Area],CavArtFreq)*CavArtYesNo

CavArtYesNo = 0

CavEnlargingBirds = 10

CavPlateAmt = 5

CavPlateFirst[A1] = 4	CavPlateFirst[A6] = 4	CavPlateFirst[A11] = 4	CavPlateFirst[A16] = 4
CavPlateFirst[A2] = 5	CavPlateFirst[A7] = 5	CavPlateFirst[A12] = 5	CavPlateFirst[A17] = 5
CavPlateFirst[A3] = 6	CavPlateFirst[A8] = 6	CavPlateFirst[A13] = 6	CavPlateFirst[A18] = 6
CavPlateFirst[A4] = 2	CavPlateFirst[A9] = 2	CavPlateFirst[A14] = 2	CavPlateFirst[A19] = 2
CavPlateFirst[A5] = 3	CavPlateFirst[A10] = 3	CavPlateFirst[A15] = 3	CavPlateFirst[A20] = 3

CavPlateFreq = 10

CavPlateInstall[Area] = Pulse(CavPlateAmt,CavPlateFirst[Area],CavPlateFreq)*CavPlateYesNo

CavPlateYesNo = 0

FireFreq = 5

FirstFire[A1] = 0	FirstFire[A6] = 0	FirstFire[A11] = 0	FirstFire[A16] = 0
FirstFire[A2] = 1	FirstFire[A7] = 1	FirstFire[A12] = 1	FirstFire[A17] = 1
FirstFire[A3] = 2	FirstFire[A8] = 2	FirstFire[A13] = 2	FirstFire[A18] = 2
FirstFire[A4] = 3	FirstFire[A9] = 3	FirstFire[A14] = 3	FirstFire[A19] = 3
FirstFire[A5] = 4	FirstFire[A10] = 4	FirstFire[A15] = 4	FirstFire[A20] = 4

FirstHerb[Area] = 5

HerbFreq = 10

HerbYesNo[Area] = 0

PltLLFFireProtection = 0

SFSCapFreq[Area] = 1

SFSCaptureRate = 0.5

SFSCaptureYesNo = 0

SFSFirstCap[Area] = 1

SFSLoss[Area] = SFSAdultMort[Area]+SFSAdultCapture[Area]

SFSPercent[Area] = IF(SFSAdult[Area]=0)THEN(0)ELSE(CavSFSOccupied[Area]/SFSAdult[Area])

WhenWildfire[Area] = 1000

WildfireIntensity[Area] = 1

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Vita

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14. ABSTRACT

The Red-Cockaded Woodpecker (RCW) is an endangered species endemic to southeastern pine forests in the United States. RCWs are cooperative breeding birds that live together in clusters of old-growth pine trees in which they construct their nesting cavities. The cavities are constructed in living pines, which are predominantly longleaf pines. RCWs also forage upon older pines, preferably longleaf pine. The Endangered Species Act, along with other DoD regulations, requires DoD installations to protect the RCWs and restore their habitat. A popular management practice converts off-site (non-native) pines back to a region's indigenous pines. Conversion provides the best long-term RCW habitat; however, the initial habitat fragmentation from off-site pine removal may be detrimental to RCW populations. Shaw AFB, SC manages a small RCW population on the Poinsett Weapons Range (PWR). Conversion from off-site slash pines to longleaf pines has been incorporated on the PWR. Shaw AFB would like to find optimal conversion rates that will not adversely affect the PWR RCW population. A spatially-explicit system dynamics model that incorporated foraging quality and group dynamics was constructed to address the conversion question. The model showed the resultant PWR RCW population level and behavior from a range of conversion settings used with different management strategies.

15. SUBJECT TERMS

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